MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XLV.

SESSION 1875-76.—PART III.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX, PAGE 374.

LONDON:

Published by the Institution,

25, GREAT GEORGE STREET, WESTMINSTER, S.W.

1876.

ADVERTISEMENT.

The Institution is not, as a body, responsible for the facts and opinions advanced in the following pages.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

CONTENTS.

Sect. I.—MINUTES OF PROCEEDINGS.

February 29, *March* 7 *and* 14, 1876.

March 21, 1876.

March 28, *April* 4 *and* 11, 1876.

SECT. II.—OTHER SELECTED PAPERS.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1875-76.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

February 29, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

No. 1,464.—"On the Floods in England and Wales during 1875, and on Water Economy."[1] By GEORGE JAMES SYMONS, Secretary to the Meteorological Society.

THE Author has, for nearly twenty years, been engaged in organising a corps of observers of the fall of rain over the British Isles. His attention has been almost wholly directed to the consideration of hydrological subjects, which include water as floating vapour, its deposit as rain, its discharge in floods, its percolation for the supply of wells, its flow into rivers, and its evaporation.

The observers, whose records form part of the basis of this Paper, now number nearly two thousand, but such is the extremely local character of many rainfall phenomena, that it is rare for any disputed question in hydrology to come before Parliament or the Courts of Law, wherein it is not obvious that data from additional stations would have been advantageous. It is only further needful to mention that, by testing the instruments in use, by visiting the stations, and by comparing the returns, the Author has endeavoured to render the returns worthy of confidence.

The number, as well as the volume, of the floods of 1875 having been extremely unusual, the Author has been led to believe that a brief record of their causes and effects, together with some remarks on other great floods of the past and present centuries, might be acceptable.

---

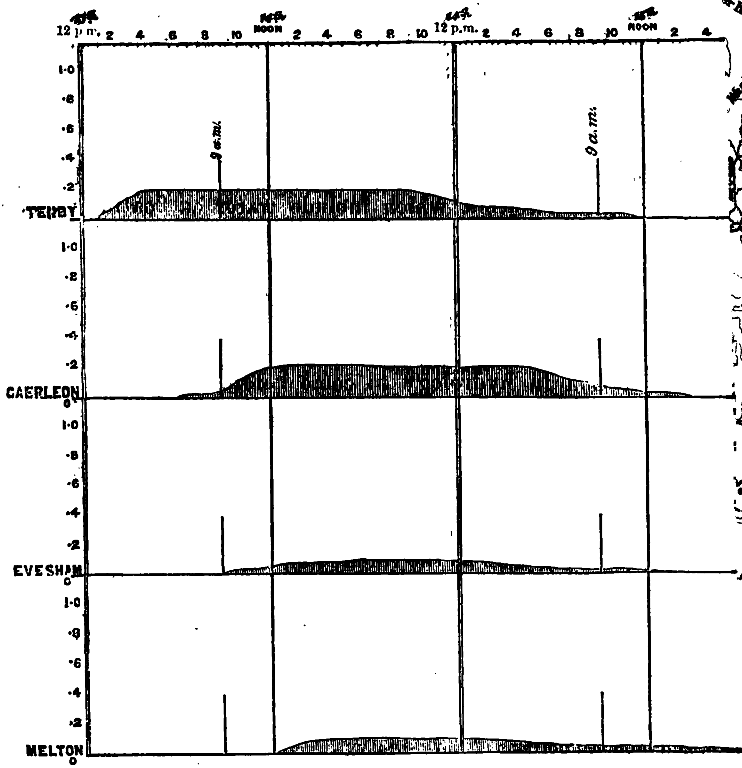
[1] The discussion upon this Paper was taken in conjunction with the following one, and occupied portions of three evenings.

The floods of July 1875 are divisible into two portions, and t
causes and consequences of each will be separately considered.

The first flood occurred on the 15th, and was the result o
rainfall of unusual amount and duration. The rain lasted, on
average, about thirty hours, but in most localities 90 or more p
cent. fell in twenty-four hours, and at some stations all fell
twenty-four hours. Plate 1 is coloured so as to show each inch
total fall; the dotted lines mark the boundaries of the princip
watersheds, and the black shades indicate injury by floods.

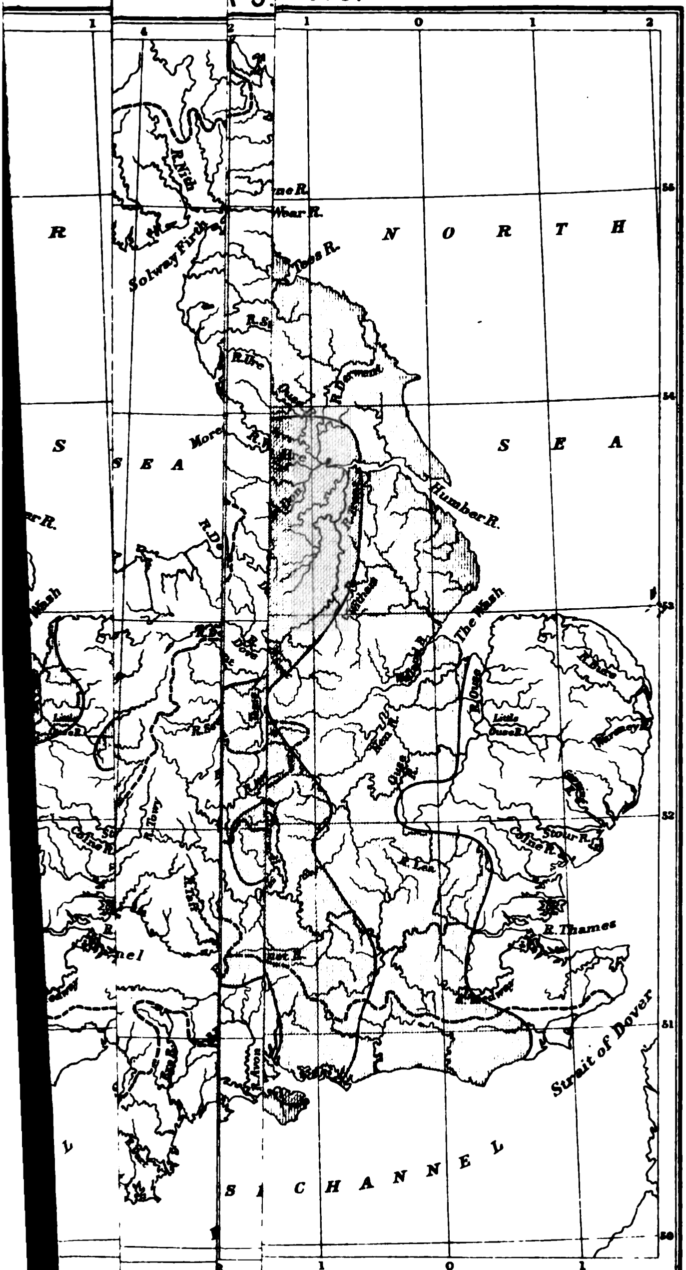
For scientific work, rigorous uniformity is essential; rainfa
observations have therefore been made punctually at 9 A.M. B
this means strict comparability of records is insured, and such evi
are avoided, as the entry of the fall during thirty-six, or even fort
eight hours against a single day. It is obvious that, whatev
hour of the day or night be adopted for the division of the rainfal
day, that dividing hour will at some stations separate a heav

FIG. 1.



ES I

R 9T 1875. PLATE 1.



Stanford's Geog. Estab.

Session 18

rainfall into two portions, neither of which may individually be remarkable; while at others, owing merely to their lying farther, or not so far, along the path of the rain-storm, the fall may be wholly in the second day or wholly in the first. This is obvious from Fig. 1, which also gives a general idea of the character of the rainfall of the 14th of July. The ordinates represent the hours from 1 A.M. on the 14th, to 6 P.M. on the 15th of July, 1875; the abscissæ indicate the depth of the rainfall per hour, in tenths of an inch.

The rainfall at stations in Monmouthshire and Glamorganshire, during the twenty-four hours ending 9 A.M. on the 15th of July, was—

	Inches.
Newport Waterworks	5·33
Tintern Abbey	5·31
Newport	5·30
Cardiff, Pentyrch	4·80
„ Ely	4·75
„ Cemetery	4·70
Caerleon	4·64
Chepstow	4·20+[1]

The exceptional character of these records will be understood when it is mentioned, that in nearly all cases the amounts are twice as great as any previously recorded at the respective stations.

The rate of advance of the rain-cloud was nearly uniform, and almost precisely 17 miles per hour, in an east-north-east direction. Fig. 1 shows that, at 4 P.M. on the 14th, when the fall of rain at Caerleon had only been 1½ inch, a telegraphic message might have been sent from Tenby, "Have had steady rain for fifteen hours, nearly 3 inches, and still continuing."

Passing now to the total rainfall, the maps (Plate 1) render it unnecessary to describe it as fully as would otherwise be requisite. As a general rule, heavy summer rains occur in thunder-storms. Occasionally water-spouts yield large amounts in short spaces of time, but they are local, and no instance is yet known to the Author of two occurrences of the class referred to in one locality. It is probable that they rarely happen twice in a century. The July rain in Monmouthshire and South Wales was not of this type, and was quite as remarkable for its steady, persistent rate of about 1 inch in each of five successive periods of five hours each, as for the total amount. It will be sufficient to give a list of the stations where a depth of 4 inches or upwards fell, which, as will be seen by the map, only occurred in two districts. The

[1] + denotes that the gauge overflowed.

fall of 4 inches on Dartmoor, though infrequent, is by no means an exceptional phenomenon, and therefore only the Monmouthshire and South Wales records are quoted. These are—

	Inches.
Tintern Abbey, Monmouth	5·91
Springfield, Newport „	5·45
Waterworks „ „	5·33
Tynant Radyr, Glamorgan	5·10
Cemetery, Cardiff „	5·05
Ely „ „	5·02
Piercefield Park, Chepstow, Monmouth . .	4·74+
Caerleon, Monmouth	4·71
Longtown, Hereford	4·70
Tenby, Pembroke	4·67
Rhymney, Glamorgan.	4·50
Abergavenny, Monmouth.	4·21
Treherbert, Glamorgan	4·14
Llanfrechfa, Monmouth	4·02+

A catalogue of injury caused by this flood would be far too long for this Paper. The Author has therefore marked the sites of the principal damage, and merely adds as brief an epitome as possible.

Bath.—The Avon rose 10 feet above its usual summer level, overflowed its banks, and flooded several streets.

Frome.—The river overflowed, and several roads were rendered impassable for pedestrians.

Cinderford, Gloucester.—The reservoir dam at the head of Blakeney Brook gave way, the effluent water swept through the town, and flooded two or more mines.

Hereford.—The Wye rose to 14 feet, being nearly as high as in the great flood of 1852.

Newport, Monmouth.—Numerous bridges were swept away.

Pontypool.—Gasworks were under water, and furnaces were extinguished.

Monmouth.—Rogers Pond reservoir near Cwm Carn burst, and is reported to have subsequently breached the Monmouthshire canal, thus sending a large body of water down the Ebbw Valley.

Cardiff.—Much of the town was under water.

The traffic on the greater number of the Monmouthshire and Glamorganshire railways was also interrupted.

The Floods of the 19th to the 21st of July. (Plate 1.)

From the 16th to the 18th, heavy rain fell in various parts, but no exceptional amount, the largest reported being near Louth, 1·36 inch, and at Halifax, 1·18 inch. On the 19th there were

thunder-storms in the Midland Counties, and in the Fen districts. Upwards of 1 inch of rain was registered at isolated stations in Northampton, Suffolk, Cambridge, Stafford, Leicester, Lancashire, and Northumberland. The heaviest falls were in the neighbourhood of Wisbeach and in the north-west of Norfolk; the maximum reported was 1·66 inch at Fincham, near Downham Market. On the 20th upwards of 1 inch of rain fell over the whole of central England, and upwards of 2 inches over a tract about 200 miles from east to west, and 30 miles from north to south. On the 21st thunder-storms, with much rain, occurred at Trowbridge, Wiltshire, and in the Thames Valley, near Reading; there was also heavy rain in the north-east of Norfolk. All the districts visited by the heavy rains of the 19th to the 21st had previously been nearly saturated by those of the 14th to the 16th; consequently the results were very serious, especially in Staffordshire and the adjoining counties. In fact, throughout the Midlands much damage was done, and many towns were inundated, including Northampton, Huntingdon, St. Ives, Burton-on-Trent, Kidderminster, Coventry, Nuneaton, &c. A canal burst near Tamworth, and railway traffic was stopped on several lines.

August was a dry month, but notwithstanding there were seven days on which falls exceeding 1 inch in depth occurred, and damage was done by floods in at least three districts, viz.: at Lewisham and the neighbourhood of Bickley, by the thunder-storm of the 7th of August, when the fall of rain amounted to about 1·75 inch, of which more than 1 inch fell in the first hour. At Enfield there was a local fall on the same day of 2·75 inches, which washed down walls, &c. There was also heavy rain in Leicester, Lincoln, and Nottinghamshire. From the 6th to the 10th a singular continuance of rain was experienced in the south-west of Cardiganshire, the total of five consecutive days at Castle Malgwyn being 4·46 inches; on the last day the banks of three ponds gave way, destroying much property, besides causing loss of life.

September was a wet month in the West of England, but about the average elsewhere. From the 1st to the 16th it presented no feature requiring notice; on the 17th a fall of 2·74 inches occurred at Bodmin, and on the 18th a fall of 1·12 inch at Haverfordwest. On the 21st there was a fall of about 0·75 inch over the greater part of England, and slight falls continued almost daily to the end of the month.

October was a very wet month, although only two individual rains require special notice—there having been a frequency of moderate falls, rather than any exceptionally large ones. During

the first three days an aggregate depth of about 1 inch fell. Then followed six almost rainless days, but on the 9th a heavy fall occurred over central England, especially in the dry district, extending north-east from Banbury towards Northampton. The fall at Banbury, and at all stations above it in the valley of the Cherwell, was 3 inches or upwards; consequently that river was excessively flooded, as was also the Avon, both at Stratford-on-Avon and at Evesham (Plate 1). During the nine following days occasional rains yielded altogether about 0·5 inch, an amount which, however unimportant *per se*, was yet sufficient to hinder rather than to facilitate the discharge of the above flood. Much land was therefore under water, and most of the rivers of central England were fuller than usual on the 18th of October, when another heavy fall of rain commenced, which lasted through the 19th and part of the 20th. During this time rain fell over the whole of England and Wales to an average depth of 2 inches. Less than 1 inch fell in the extreme south-west of England, in Pembrokeshire, and in the eastern and south-eastern counties of England. Upwards of 3 inches fell over part of Staffordshire, and at Exeter; the amount at the latter place being principally due to a torrential rain of 3·26 inches in a few hours. This was a phenomenon producing much local, but no general damage. It was far otherwise in the great Midland tract, which had received a depth of upwards of 2 inches of rain. The ground being saturated, or nearly so, all the low-lying lands were flooded, and the total area under water was probably greater than it had been for many years; certainly since 1852, the only recent case with which it could be compared.

From the 1st to the 18th of November the weather continued of the same rainy type as during the last half of September, and the whole of October. The result was that nearly the whole of the land flooded at the end of October remained so until the latter part of November.

The distribution of rain over England in July, September, October, and November 1875, is given in the Appendix, Tables A, B, C, and D.

Details of the Height of the River Cherwell at Oxford, and of the River Avon at Stratford-on-Avon and at Evesham.

On the 9th of October, 1875, the Rev. T. H. Hopkins, Tutor of Magdalen College, Oxford, placed in the river Cherwell, where the river forms the boundary of the College meadow, a scale, the base

of which is a flat stone. This stone has only once been known to be dry, and the level of its upper surface is the zero of the observations. Mr. Chapman, of Frewen Hall, remarks that the recent floods seem to have been almost exactly equal to those of 1852, and that the rise of the river follows the rain at an interval of about thirty-six hours.

At Stratford-on-Avon a flood board was placed by the bank of the river at the Stratford flour mills at the beginning of the present century, and every occasion when the floods have risen to 4 feet above the weir has been recorded. Messrs. C. Lucy and Nephew, in sending the following list, remark, that of a total of ten floods which have exceeded 4 feet in height, four were in 1875, being the only instance where more than one flood has reached over the 4 feet in the same year.

		Feet.	Inches.
1801	(Date unknown)	7	2½
1821	December 25th	5	8½
1848	October 1st	6	4½
1852	November 12th	5	10½
1853	July 15th	5	5
1872	December 14th	5	4
1875	July 22nd	6	8
„	October 12th	4	9
„	„ 21st	6	0½
„	November 14th	5	9

Observations at Evesham, 16 miles lower down the river, gave nearly the same results, the slight differences probably being due to the tributaries the Avon receives between Stratford and Evesham.

		Above ordinary level. Feet.	Inches.
1770	November.—The highest flood within memory; it reached almost up to the keystone of the middle arch of a bridge, of which no accurate record exists, probably	15	0
1830	June 26th.—Violent thunder-storm; the river during the night rose from its usual level to about	14	0
1848	October 1st.—A three days' rain caused the river to rise rapidly; the flood can only have been second to that of 1770	14	9
1852	November 11th.—Greatest height	14	0
1872	January 18th.—A flood of long duration; for seventy hours it exceeded	7	0
	And its maximum was	8	9
1875	July 22nd.—Maximum at 4 P.M.	12	6
„	October 10th. „ 4 P.M.	9	6
„	„ 21st. „ 4 A.M.	13	1
„	„ 28th. „ 4.30 P.M.	4	6
„	November 7th. „ 8 A.M.	8	6
„	„ 12th. „ 4 A.M.	10	0
„	„ 14th. „ 3 P.M.	12	0

Having briefly indicated the locality and features of the floods of 1875, attention is necessarily led to their cause and prevention.

There are three primary branches of inquiry respecting the development of floods, upon which the Author can throw no light for want of observations. These branches are: (1) The rate of rise of floods. Beyond the general fact, which lies upon the surface, that a torrential rain, like that of 3·26 inches in three hours at Exeter, produces a rapid rise in the nearest stream, scarcely anything is known. It must be perfectly possible to compute, from the nature of the soil, the inclination of its surface, and the rainfall, the rate of rise in the rivers, but scarcely anything is done, and little more is known now than in former days. Similarly with respect to (2), the relative floods on different soils; it is known that floods on chalk are rare, not occurring except under the unusual conditions mentioned by Mr. Homersham, M. Inst. C.E.;[1] it is also known that in precipitous districts of primary rocks they rise and fall with great rapidity, but no attempt to deduce the rate, on, say, oolitic, as compared with primary, rocks, has been made. (3). The Author is not aware of any published details of the rate of progress of floods down rivers in England, although he possesses many such records for foreign rivers. Obviously floods are the result of rain falling upon the ground faster than it can run off. The flatter a river the less its velocity; the nearer "bank full" a river is kept, the less the storage room it possesses, and the sooner does it begin to overflow.

Thames floods might be abated either by embanking, by constructing storage reservoirs, or by lowering the water-level. Embanking has been much urged as a remedy for floods, but to the Author it seems of doubtful expediency, except within tidal limits, the effect of embanking being always to raise the bed of the river. Another feature with respect to embanking, and one of special importance in a flat watershed like the Thames, where the rainfall varies but little, is, that while embanking secures the exclusion of water from above, it at the same time checks the facility of discharge from land behind the embankment.

There is at present a popular demand that the flood waters of the upper Thames should be stored. This storage will vary greatly according as it is designed for (1) preventing floods, (2) or for maintaining an adequate flow during droughts. It is a different matter to store flood water in the Thames from what it is in

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 53.

many other rivers, such as the Severn, for instance. The Thames valley, as far as the Author is aware, is singularly destitute of good natural sites for reservoirs; and their construction though practicable, would be costly and difficult; costly from the extent and nature of the works, and difficult owing to the porosity of much of the soil. The Author doubts whether those who urge the storage of the winter floods of the Thames realise the enormous volume of water to be dealt with. A depth of 1 inch of rain over the Thames basin above Kingston gives 53,375,000,000 gallons.[1] If the reservoir storage is to be adequate to prevent floods, a depth of rain of at least 3 inches must be provided for, or, in round numbers, 160,000,000,000 gallons. Even then it is doubtful whether it would at all times be possible to lower the reservoirs with sufficient rapidity to be ready for subsequent rains, without the discharge of such a volume of water as to risk slight floods. Again the responsibility for the control of such reservoirs would be exceptionally onerous, for the Engineer would always be expected to have the reservoirs empty when a flood came, and yet would be blamed if they were not full at the commencement of a drought. Mr. Bailey Denton, M. Inst. C.E.,[2] proposed for water supply purposes certain reservoirs in the Thames basin having an aggregate capacity of 14,500,000,000 gallons, and he estimated their cost at £1,360,000. At this rate of £5,000,000 sterling for the storage of 1 inch of rainfall, reservoirs of adequate capacity to prevent the flooding of the Thames would cost at least £15,000,000 sterling. This, perhaps, is a sufficient reply to the suggestion of storage solely as a remedial measure against floods. It would, however, probably be judicious to examine the watershed, to ascertain whether sites for small reservoirs exist on the Thames or its tributaries, and if suitable ones exist to have them utilised. This is especially desirable as long as the supply of water to London for drinking purposes is taken from the Thames; and part of the cost might justly be thrown upon the companies pumping therefrom.

The Author does not wish to discuss at length the expediency of retaining the weirs on the Thames at their present height. He may, however, be permitted to express his concurrence with the remarks of the Rivers Commission,[3] respecting the relative importance of water-mills and agricultural land, and to state his

---

[1] *Vide* Royal Commission on Water Supply, Minutes of Evidence, p. 183.

[2] *Ibid.*, p. 100.

[3] *Vide* "Second Report of the Commissioners appointed to inquire into the best means of Preventing the Pollution of Rivers. River Lee." Vol. i., p. xvi. 1867.

belief, that the vested rights of a few miserably unprofitable mills should not be allowed to cause the flooding of thousands of acres. The more rapid discharge of flood waters is perfectly practicable, but its expediency is too large a question to be raised incidentally. Hitherto no adequate attempt has been made to grapple with the evil; this can only be done by the action of Government, and by giving larger powers and larger pecuniary assistance than heretofore. Up to the present time every attempt to improve rivers or to provide towns with water has been met by a powerful association of vested interests of the class already described. Whether the owners of these obstructions ought not to give way is a political rather than an engineering question; but it may be safely affirmed, that it is most desirable that, if any works be proposed for the Thames valley, or for any other watersheds, the amount expended in compensation should be separated from the sum spent in works.

Considering that the health of the nation depends on the purity of its water supply, and considering also the multitude of uses of water for manufacturing purposes, and the great pecuniary losses resulting from floods, it seems remarkable that there is in England no central body charged with the supervision and control of a matter so important to the national welfare. It is believed that if a central office had existed, thoroughly informed of the depth of the rainfalls, with power to telegraph the information to local officers; and if these local officers had had all sluices, &c., under their absolute control, much of the recent damage might have been averted.

The quantity and quality of water are so frequently considered together, that the Author ventures to say a few words upon the latter question. The purity of the water supplied for drinking purposes is evidently of the highest importance; and since the discovery of the conveyance of disease germs through the mixture of excremental matter, even with large volumes of water, the paramount necessity of avoiding all sources which show any trace of previous sewage contamination can hardly be contested. This is especially the case since Dr. Frankland has shown that the theory of the self-purification of rivers by oxidation, even if it occurs at all, is certainly not universal.

It is not now, however, merely town or village drainage which it is necessary to guard against; there is also the by no means agreeable drainage from highly-manured land. It appears, therefore, to follow that all sources must be abandoned except uncultivated mountain districts and deep wells. But cultivation has advanced so rapidly in England and Wales, that the uncultivated

area is becoming very small, and is insignificant except in Devonshire, Wales, parts of Yorkshire, and the Lake Districts. No one would be so rash as to propose that the drinking water of all England should be obtained from these districts. Besides, chemists object to many of the gathering grounds on account of mineral workings, and to others because the water is discoloured a little by peat. Latterly, moreover, microscopists have come forward to urge that the water in which, perhaps, the chemist can detect but a trace of organic matter, is proved, under the microscope, to contain numbers of animalcules.

Are, then, deep wells to be the sole source for the supply of water for the future? Here the question of hardness suggests itself for consideration. Probably the most desirable water for a town supply is one of moderate hardness, not a chalk water which will scarcely allow washing in comfort, nor an excessively soft water, which is alike deficient in refractive power (or, as it is popularly termed, brilliancy), and in crispness of taste. But there are great difficulties in obtaining an adequate supply from wells, and there is also the cost of pumping. Moreover, as has been proved at Rugby, it by no means follows that good water can always be obtained by sinking a well. There can hardly be any question respecting the necessity of rejecting water showing traces of previous sewage contamination, for disease germs appear to possess a vitality proportional to their destructiveness. With reference to the fouling of water by artificial manures, the Author was shown, on the farm of Messrs. Lawes and Gilbert at Rothamstead, two patches of wheat; each had been sown at the same time, and each had received the same total quantity of manure, yet one patch was greatly superior to the other. The explanation was that the date of application of the manure had been different. One patch received the whole amount in the autumn; the other only a slight amount in the autumn and the residue in the spring. The autumnal and winter rains washed away the bulk of the manure applied in the autumn, which did little good to the wheat, and (as was proved by analysing the effluent drainage water) ran into the streams and did harm. It must be admitted that a small amount of artificial manure is carried into the streams; but it remains to be shown that the amount is sufficiently large to be injurious.

The pollution of mountain water by mining operations may next be mentioned; but this is a sentimental rather than a real injury. No one would like to drink a tumblerful of the water from Greenside mines as it passes down Glenridding beck as white as milk, or from a stream of "Hush" water; yet let the tumbler stand for

a few hours, the earthy matter would fall to the bottom, and the water, if not quite as pure as it fell on the mountainside, would be far superior to that with which too many of the population are supplied, and which has served them and their ancestors for generations. Dr. Frankland himself has stated [1] that the exclusion of the Glenridding stream would be an injury to Ullswater.

Peaty water is objected to, and is neither agreeable to sight nor to taste; but, unless it be nearly as brown as coffee, it is doubtful whether it is unwholesome. At any rate, the population who have no other supply are usually healthy and long-lived.

Animalcules are unpleasant additions to drinking water; but if equal microscopic power were applied to other articles of food, our dietary would probably be very limited. Ever since man has been upon earth he has drunk from mountain streams, and if such streams contain animalcules, it seems necessarily to follow that they cannot be very injurious.

Well and spring water is usually free from organic matter, and therefore is recommended for almost universal adoption; but Drs. Frankland and Odling state,[2] when referring adversely to the well-water which the Kent Company pump from the chalk, that "it is remembered that the chalk of the London basin receives a large amount of soakage from cultivated land; secondly, that the chalk wells of Woolwich Arsenal betray symptoms of connection with the river Thames; and thirdly, that the chalk itself is, according to the recent researches of Béchamp, filled with living microscopical organisms. The presence of large quantities of nitrates in the chalk waters of the Kent Company is by no means exceptional; these salts exist in still larger quantities in the chalk waters of Grays, Worthing, and Watford." Without accepting *in toto* the catalogue of evils with which the Board of Health charged hard water, it is difficult to consider that the quantity of mineral matter which it contains can be without effect. If asked to believe that large quantities of carbonates or sulphates of lime are inert, one instinctively feels that, if that be true, the efficacy of nearly all the mineral spas of Europe must depend not upon the silicates, &c., in the water, but upon the imaginative power of the drinkers.

Rain was formerly considered the purest source of water available; but now a Royal Commission [3] state that it is "water which has washed a more or less dirty atmosphere," and that it is "laden

---

[1] *Vide* Royal Commission on Water Supply, 1869, Appendix D, p. 22.

[2] *Ibid.*, p. 21. [3] Rivers Pollution Commission, 1868. Sixth Report, p. 30.

with mineral and excrementitious dust, zymotic germs, and the products of animal and vegetable decay and putrefaction." These sweeping assertions are followed by analyses, and it is stated that we shall "look in vain to the atmosphere for a supply of water pure enough for dietetic purposes." There is a simple and apparently convincing proof that these alarming statements may be received with perfect equanimity. The population in England wholly dependent upon rain water is a large and an increasing one. If rain water, when collected with moderate prudence, is unwholesome, surely the Commission, which spared neither trouble nor expense in other matters, would have produced evidence of the illness resulting from the use of rain water.

The extreme refinement of modern analysis has seemingly led chemists to set up a standard of purity in excess of the necessities of the case. Every one engaged in selecting a source of water supply looks out for the best obtainable at a reasonable cost: it can scarcely be expected that more should be done. Of the total supply, probably not one-hundredth part is drunk, and not one-thousandth cold and unmixed with other ingredients. It is hard that nine hundred and ninety-nine parts must be of ideal purity, for the other one that may be drunk, especially considering that the better class of domestic filters will remove any injurious substance.

Looking forward to the time when the extension of cultivation and the increase of the population will render necessary important changes in the water administration of this country, the first and great point is to secure the highest possible training for the rising generation of engineers. The Author believes that in two respects students in France have a material advantage over those in England. It may appear strange to complain, in an Institution whose library of engineering works is probably unequalled, that English students of hydraulic engineering are badly provided for. It is, however, certain that, as regards books upon rivers or canals, there are at least ten times as many published in France as in England.[1]

English engineers very rarely write books; consequently the only resource of a young engineer is a pile of blue-books, which he must sift and digest as well as he can. Another deficiency is that

---

[1] The catalogue of second-hand books just issued by Lefèvre, of Paris, contains thirty-one separate French works on hydrology, canals, and rivers. This one catalogue, therefore, probably mentions more separate works upon the subject than have ever been printed in England.

of an Institute for Experimental Instruction in the Laws of Hydrology. The Author has long regretted the absence of such an institution in this country, and the regret has been much increased since M. Hervé Mangon kindly took him through the hydrological school at Paris, belonging to the department of the Ponts et Chaussées. The appliances provided in that establishment are, as far as the Author is aware, neither equalled nor approached in this country; for they do not merely consist of chemical laboratories, geological museums, and such ordinary implements of tuition, but include machine-rooms, models, and apparatus for testing the flow of water, with varying heads, through orifices of various sizes and shapes; thus giving that practical familiarity with hydrological observations and experiments in early youth which would be of service through life.

The Paper is accompanied by a series of diagrams, from which Plate 1 and Fig. 1 have been compiled.

[APPENDIX.

APPENDIX.

TABLE A.—DEPTH OF RAIN, JULY 1875.

	Over the Thames Valley.												Over all England.						
Date.	Cirencester.	Compton Bassett.	Banbury.	Oxford.	Wantage.	Strathfield Turgiss.	Selborne.	Great Missenden.	Horsham, Swallowfield.	London, Camden Square.	Harlow.	Maidstone, Linton Park.	Culford.	Bodmin.	Shiffnal.	Boston.	Manchester.	York.	Haverfordwest.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1	..	·02	..	·06	·08	·02	·18	..	·24	·17	·15	·54	·52	·14	·03	·07	..	·01	·17
2	·38	·88	·36	·33	·15	·06	·62	·13	..	·17	·01	..	·01	·27	·52	..	..	..	·05
3	·14	·10	·33	·14	·21	·31	·04	·42	·02	·24	·34	·70	·56	·01	·24	·25	..	..	·01
4	..	..	..	..	..	..	..	..	..	..	..	·33	..	..	..	..	·88	..	..
5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
7	..	..	..	..	..	..	..	..	·18	..	..	..	..	..	..	..	..	·10	..
8	..	..	..	·05	..	..	·34	..	..	·01	..	·12	..	·07	·05	·07	..	·12	·13
9	·17	·47	·31	·18	·29	·51	·03	·62	·24	·38	·34	·08	·29	·20	·52	·52	·42	·25	·13
10	·38	·43	·24	·25	·30	·05	·13	·15	·08	·07	·07	·08	·02	·23	·21	·08	·32	·14	·59
11	·02	·03	·34	·06	..	·02	..	·25	·28	·22	·11	·61	·09	·01	·18	·13	·07	·03	·05
12	..	..	..	..	..	..	..	..	..	..	·01	·05	·01	..	..	..	..	·10	..
13	·15	·03	..	·03	·04	..	..	..	..	..	·01	..	..	·86	..	..	..	·13	·97
14	3·11	2·37	1·36	1·70	1·75	1·64	2·14	1·36	1·32	1·29	·97	·10	·84	1·36	1·24	·72	·39	..	2·41
15	·36	·34	·39	·42	·92	·84	·73	1·10	1·33	·93	·18	·95	·49	..	·42	·36	..	·63	·13
16	..	..	..	..	..	·02	·08	·12	·33	·26	·07	1·45	..	..	..	..	..	..	..
17	·16	·38	·09	·23	·50	·25	·13	·15	·15	·17	·16	·16	·02	·08	·06	·20	·18	·56	·33
18	..	..	·06	·15	·10	·06	..	·08	·06	·07	·02	..	..	·12	·11	·18	·26	·54	·05
19	..	·08	·11	·05	·05	·02	·28	..	·01	·03	·53	·13	·38	·06	·37	·46	1·06	·17	..
20	·50	·18	1·56	·67	·34	·01	..	·19	..	·02	·16	..	1·05	..	1·32	·56	·73	·20	..
21	·07	·03	·17	·24	·20	1·78	·51	1·62	·41	·43	·92	·23	·98	·08	·03	·17	·05	..	..
22	..	·08	·06	..	..	..	·37	..	·02	·03	·01	·05	·03	·03	·23	..	·02	..	·21
23	·04	·20	..	·01	..	·11	·81	·05	·84	·15	·07	·01	..	·05	·01	·01	·11	·04	·24
24	·08	..	·01	·02	..	..	·03	·09	·02	..	·01	·01	..	·01	·03	..	..	..	..
25	..	..	..	·11	·05	..	·04	..	·16	..	·01	..	..	..	..	·04	·04	..	..
26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
27	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·03	..
29	..	·01	..	..	..	..	..	..	..	..	..	..	..	..	·02	..	·07	..	·03
30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
31	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Totals	5·56	5·63	5·39	4·70	4·98	5·70	6·46	6·33	5·69	4·64	4·15	5·60	5·29	3·58	5·59	3·82	4·60	3·05	5·50

TABLE B.—DEPTH OF RAIN, SEPTEMBER 1875.

	Over the Thames Valley.												Over all England.						
Date.	Cirencester.	Compton Bassett.	Banbury.	Oxford.	Wantage.	Strathfield Turgiss.	Selborne.	Great Missenden.	Horsham, Swallow-field.	London, Camden Square.	Harlow.	Maidstone, Linton Park.	Culford.	Bodmin.	Shiffnal.	Boston.	Manchester.	York.	Haverford-west.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches	Inches.
1	..	..	..	..	..	..	..	..	..	..	..	..	·15	·07	..	·03	..	..	·05
2	..	·20	·08	·16	·20	..	..	..	..	..	..	..	..	·68	·50	·02	·83	..	1·81
3	·31	·10	·10	·07	..	·12	·16	·28	·14	·17	·11	·07	..	..	·10	·22	·39	·83	..
4	..	..	..	..	..	..	..	..	..	..	·01	..	..	..	..	..	·07	..	..
5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
6	..	..	..	..	..	..	..	..	..	..	·01	..	..	..	..	..	..	..	..
7	..	·01	..	·03	..	..	..	..	·01	·01	..	..	..	..	..	·01	..	..	..
8	·10	·05	·05	·02	·04	..	..	..	..	·01	·01	..	..	·04	·28	·04	1·00	·12	·20
9	·12	·28	..	·02	..	·01	..	..	..	..	..	..	·04	·46	·03	..	..	..	·26
10	..	..	..	..	..	..	..	..	..	..	·07	·21	·16	..	..	·06	..	..	..
11	..	..	..	..	..	..	..	..	..	..	·01	..	..	..	..	..	..	..	..
12	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
13	..	..	..	..	..	..	..	..	..	..	..	·01	..	..	..	..	..	..	..
14	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
16	..	..	..	..	..	..	..	..	..	·36	·09	..	..	·08	..	..	..	..	..
17	..	..	..	..	..	..	..	..	·15	..	·01	·02	..	2·74	..	..	..	..	..
18	..	..	..	..	·02	..	..	..	..	..	..	..	..	·31	·05	..	..	·38	1·12
19	·30	..	·10	·20	·25	·43	·24	..	..	·01	..	..	..	·07	·83	..	·51	..	·01
20	..	·04	·01	·03	·05	·13	·02	..	·10	·06	..	..	..	·22	·19	..	..	..	..
21	·77	·71	·89	·66	·80	·52	·49	·75	·49	·73	1·05	..	·85	1·06	·58	·60	·64	·17	1·06
22	·14	·12	·20	·12	·13	·06	·30	·17	·07	·16	·08	·54	·12	·51	·02	·14	..	·49	..
23	·43	·24	·67	·33	·27	·27	·21	·60	·23	·78	·68	·45	·39	..	·65	·45	·51	·21	·60
24	·12	·22	·07	·03	·04	·02	·10	·07	·25	·12	·38	·34	·30	·17	·39	·45	·02	..	·45
25	..	·05	·02	..	..	..	·03	·07	·07	·22	·10	·27	·01	..	..	·02	·11	·03	·06
26	·08	·23	·04	·01	·09	·02	·05	..	·08	·01	·02	·09	..	·41	·02	..	·13	..	·17
27	·15	·49	·09	·20	·12	·05	·14	..	·10	·15	·10	·07	·10	·37	·30	·07	·25	..	..
28	·28	·34	·03	·06	·06	·26	·13	·10	·15	·05	·07	·13	·53	·34	·11	·03	·11	..	·08
29	..	..	..	..	..	..	..	..	·01	..	..	..	·02	·01	·04	..	·13	..	·02
[illegible]	[illegible]	[illegible]	·02	[illegible]	[illegible]	·01	[illegible]	[illegible]	·07	·02	·04	..	..	·10	·05	·10	·01	..	·40

Date.	Over the Thames Valley.												Over all England.						
	Cirencester.	Compton Bassett.	Banbury.	Oxford.	Wantage.	Strathfield Turgiss.	Selborne.	Great Missenden.	Horsham, Swallowfield.	London, Camden Square.	Harlow.	Maidstone, Linton Park.	Culford.	Bodmin.	Shiffnal.	Boston.	Manchester.	York.	Haverfordwest.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1	·20	·08	·16	..	..	·10	·44	·15	·63	·23	·24	..	·22	·45	·07	·05	·14	..	·36
2	·66	·80	·40	·87	·70	·33	·24	·58	·15	·41	·64	·91	·74	·21	·09	·03	·05	..	·36
3	·21	·26	·08	·20	·41	·15	·30	·15	·33	·33	·13	·24	·15	·27	·23	·08	·23	·05	·50
4	..	..	..	..	..	..	..	..	·01	..	·01	·10	..	·03	..	..	·09	..	·51
5	..	·02	·06	..	..	..	·06	..	..	·20	..	·02	·05	·02	..	..	..	·03	·12
6	..	..	..	..	..	..	..	..	..	..	..	..	..	·01	..	..	..	..	·01
7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
8	..	..	..	..	..	..	..	..	..	..	..	..	..	·25	..	..	..	..	·05
9	1·74	1·38	3·25	1·72	1·58	·16	·07	1·25	·03	·14	·39	·02	·18	·11	·76	·58	·40	·13	..
10	·35	·28	·20	·28	·20	·26	·44	·33	·34	·22	·25	·02	·20	·44	·14	·18	·30	·58	·20
11	·04	..	·03	·12	..	..	..	..	..	·05	·01	·19	..	·62	·0[illegible]	..	·74	..	·50
12	..	..	..	..	·02	..	·11	..	·02	..	..	·01	..	·28	·02	..	·02	..	·11
13	..	..	..	·01	..	..	·02	·25	..	·04	..	..	..	·58	..	..	..	·02	·18
14	·11	·18	·29	·14	·14	·16	·13	·03	·19	·13	·05	·24	·24	·03	·13	·53	..	..	·07
15	..	·02	·01	·02	..	..	..	..	..	·03	·01	·31	..	..	..	·04	..	·28	..
16	..	..	..	..	..	..	..	..	..	..	·01	..	..	·31	..	..	..	..	..
17	..	..	..	..	..	..	..	..	..	..	..	..	..	·06	·04	..	..	·03	·65
18	·70	·48	·58	·66	·50	·54	·70	·75	·72	·78	·35	·01	·14	1·31	·62	·21	·10	·22	..
19	1·15	1·12	1·19	1·66	1·85	1·65	1·45	·60	·87	·29	·12	·25	·04	·01	1·27	·16	·90	·54	·64
20	·19	·10	·77	·47	·30	·35	·15	·56	·14	·72	·63	·47	·60	..	·58	1·39	·83	1·25	·02
21	·40	·64	·17	·15	·18	·25	·23	·17	·52	·26	·12	·20	·18	·37	·16	·10	·31	·12	·05
22	·70	·86	·04	·13	·60	1·08	·70	·42	·94	·06	·18	·26	·13	·39	·26	·07	·14	·48	·80
23	·30	·27	·02	·27	·50	·01	·02	·37	..	·25	·11	·34	·26	..	·01	·08	..	·22	·62
24	..	..	..	..	..	..	..	..	..	..	·01	·08	..	..	..	..	..	..	..
25	..	..	..	..	..	..	..	..	..	..	..	..	..	·34	..	..	..	..	·33
26	·60	·47	·22	·43	·45	·37	·16	·11	·12	·17	·11	..	..	1·80	·36	..	·21	..	·14
27	·31	·52	·23	·13	·24	·31	·33	·22	·09	·04	·10	·10	·11	·12	·30	..	..	..	·22
28	..	·16	·10	·15	·22	·13	·28	·14	..	..	·01	·08	..	..	·26	..	..	·05	..
29	·16	..	..	..	..	..	..	..	..	..	..	..	..	·26	..	..	..	·06	·14
30	..	·02	..	..	..	..	..	..	..	..	·01	..	..	·31	..	..	..	·09	·28
31	..	..	..	..	..	..	..	..	..	..	..	..	..	·48	..	..	..	·06	·42
Totals	7·82	7·66	7·80	7·41	7·89	5·85	5·83	6·08	5·10	4·35	3·49	3·85	3·24	9·06	5·32	3·50	4·46	4·21	7·28

TABLE D.—DEPTH OF RAIN, NOVEMBER 1875.

Date.	Over the Thames Valley.												Over all England.						
	Cirencester.	Compton Bassett.	Banbury.	Oxford.	Wantage.	Strathfield Turgiss.	Selborne.	Great Missenden.	Horsham, Swallow-field.	London, Camden Square.	Harlow.	Maidstone, Linton Park.	Culford.	Bodmin.	Shiffnal.	Boston.	Manchester.	York.	Haverford-west.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1	..	·05	..	..	..	..	..	..	..	..	..	..	..	·68	..	..	..	..	·60
2	·22	·13	·04	·02	·05	·06	·13	·05	·06	·01	·03	·01	..	·44	·33	·14	..	·79	1·00
3	·06	·07	·06	·05	·12	·06	·10	·07	·04	·01	·01	·05	·02	·11	·04	·01	..	·04	·15
4	..	·05	·01	..	·04	..	..	..	..	·01	·01	·05	..	·05	·02	..	..	·04	·01
5	·66	·48	1·00	·58	·42	·48	·64	·60	·61	·56	·54	·20	·80	·86	·50	·47	..	·15	1·01
6	·04	·11	·11	..	·02	·25	·11	..	·05	·02	·03	·42	·24	·10	·09	·54	..	·23	·10
7	·57	·52	·43	·53	·58	·43	·44	·61	·79	·40	·52	..	·41	·61	..	·02	..	·02	·84
8	·10	..	..	..	..	..	..	..	..	..	..	·87	..	·04	..	..	..	..	·18
9	·55	·17	·54	·36	·27	·37	·70	·31	·58	·37	·38	..	·60	·76	·64	·70	..	·21	·78
10	·71	·61	·64	·80	·65	·52	·73	·63	..	·67	·87	·30	·89	·90	·20	·21	..	·10	·38
11	..	..	..	..	..	..	..	..	..	..	·01	·68	·05	·19	..	..	..	·10	·05
12	·38	·42	·20	·36	·25	·35	·52	·20	..	·30	·19	..	·09	1·07	·32	·08	..	..	·34
13	1·12	·70	1·12	·59	·73	·48	·67	·90	..	·44	·59	·60	·78	·99	·63	·93	..	1·03	1·17
14	·16	·10	·15	·02	·05	·02	·19	·05	2·14	·03	·18	·23	·17	·03	·03	·03	..	·08	·32
15	..	..	..	..	..	..	..	..	..	..	..	·03	..	·10	..	..	..	·03	·02
16	·25	·30	·25	·18	·32	·29	·19	·37	..	·36	·26	·02	·21	·07	·32	·10	..	·19	·30
17	·16	·10	·12	·10	·08	·07	·13	·06	..	·07	·05	·21	·19	·01	·12	·20	..	·17	·20
18	·06	·15	·04	·06	..	·01	·10	·07	..	·02	·01	·02	·01	·10	·12	·02	..	·05	·04
19	..	..	·02	·04	..	..	..	..	..	·01	·02	..	·12	·01	·02	·04	..	·04	·10
20	..	..	..	..	..	..	..	..	..	..	·01	..	·37	..	..	·25	..	·03	·02
21	..	..	·01	..	..	..	..	..	..	..	..	..	·05	..	..	·06	..	..	..
22	..	..	·01	·02	..	..	..	..	..	·01	..	·09	·06	..	..	·07	..	·04	..
23	..	..	·01	..	..	..	·03	·10	·02	..	..	·16	..	..	..	·18	..	·11	..
24	..	..	·01	..	..	..	·02	..	..	..	..	·03	·05	..	..	·05	..	..	..
25	..	..	..	..	..	..	..	..	..	·02	·02	·03	..	..	..	·07	..	·11	..
26	..	..	·02	·01	..	..	..	..	..	..	·01	·03	..	..	..	·25	..	·17	..
27	..	·02	·01	·03	..	·03	·02	..	·02	·01	·03	·11	·15	..	..	·34	..	·04	..
28	..	..	..	..	..	..	·01	..	·02	·01	·01	·18	..	..	·16	·04	..	..	..
29	..	·02	·03	·03	..	..	..	..	..	..	..	·02	..	..	..	·05	..	·06	..
30	..	·02	·01	·02	..	..	..	..	·04	·02	..	·05	..	..	·02	·05	..	..	..
Totals	5·04	4·02	4·84	3·80	3·58	3·42	4·73	4·02	4·37	3·35	3·78	4·39	5·26	7·12	3·56	4·90	4·23	3·83	7·61

No. 1,409.—"On Evaporation and on Percolation." By CHARLES GREAVES, M. Inst. C.E.[1]

WHETHER the descent of rain or the ascent of vapour be the more important natural phenomenon may perhaps be a difficult question to decide. There can, however, be no doubt that, hitherto, the study of the first and the measurement of rainfall have received the greater degree of attention. It is with a view to obtain a more systematic, and at the same time practical, series of observations of the latter that the Author has undertaken this Paper. After having carried on such observations, he has found them afford new and important information; and he hopes to secure co-operation so as to enlarge the exact knowledge of atmospheric evaporation, now unfortunately very limited.

The quantity of water which the inhabitants of this earth, in any part, have to deal with is the result of the operation of two series of forces, one tending to increase, the other to diminish it. The measurement of rainfall, by the quantity collected, has always this practical advantage, that it is total and real, and the water in hand is an accomplished fact; but the knowledge of evaporation, as now generally acquired, is merely a deduction from the capacity of the atmosphere to evaporate. The endeavour of the Author has been to give this also a practical form, and at the same time to avoid prejudice to the observations by a too frequent emptying of the measuring vessel, or from local and accumulated heat causing undue evaporation in it.

It is the purpose of the Author to enter into a discussion of maxima and minima—of total and periodic quantities, such as those of

Rain falling,

Rain percolating through ordinary ground, and re-evaporated from it,

Rain percolating through sand, and re-evaporated from it,

Water evaporated from a water surface by a natural process, and their co-relation.

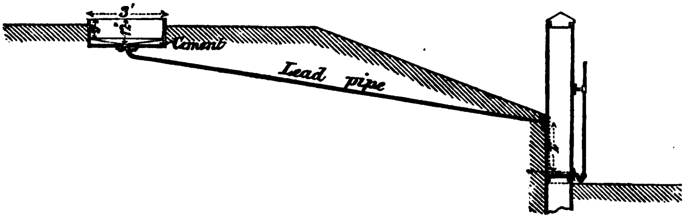
Ever since the year 1850 the Author has felt how desirable it would be to confirm the interesting reports then given by Mr. Dickinson to this Institution,[2] on the percolation of rain through

[1] The discussion upon this Paper was taken in conjunction with the preceding one, and occupied portions of three evenings.

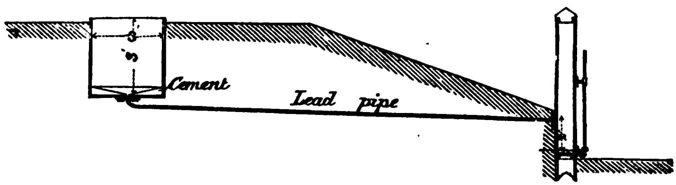
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 158.

a medium representing natural soil, and he resolved to establish a similar gauge and register. The gauge was set in October 1851, but suffered some interruption previous to the beginning of 1855, since which time the register has been maintained continuously.

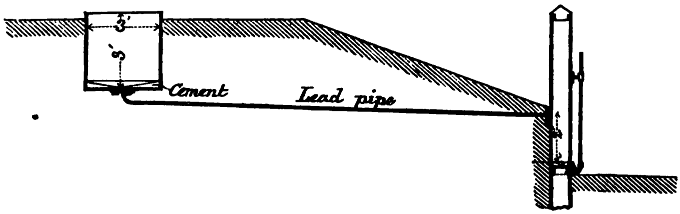
Fig. 2.



Rain Gauge.



Ground Gauge.



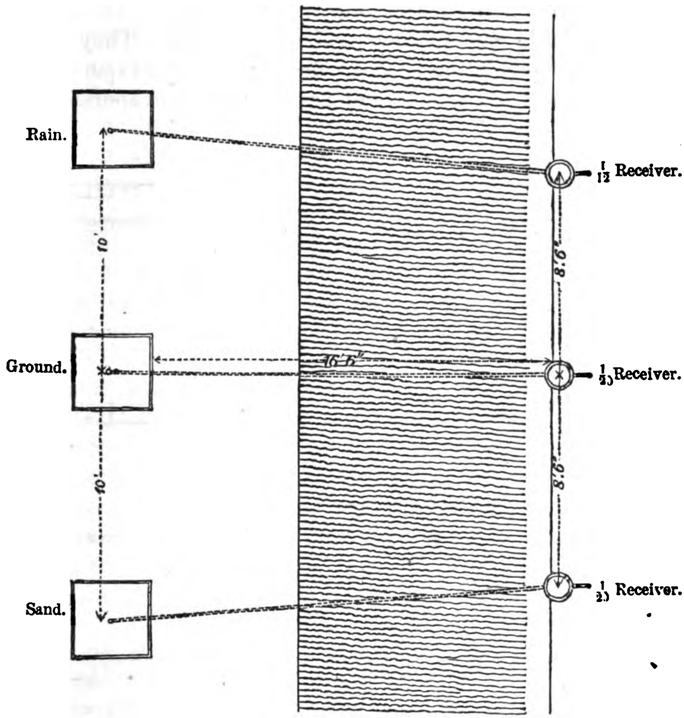
Sand Gauge.

The area of each of these gauges is 1 square yard, that of the receiver is $\frac{1}{12}$ in the rain gauge and $\frac{1}{20}$ in the ground and sand gauges. The edge of each is about 2 inches above the outside ground. The earth in the second is trodden, but not beaten, and is intended to represent ordinary average agricultural soil in grass; the third was filled with filter-bed sand.

The gauge (Figs. 2 and 3) is on the principle known as a "Dalton Gauge," and is thus constructed: A strong slate, open-topped, watertight box or tank, with an area of 1 square yard and 1 yard deep, has connected to the middle of its bottom a lead pipe, which is led to another fixed vessel with a close bottom, set upright as a receiver, and with its base placed several feet below the tank. A glass gauge pipe is fitted to the side of the receiver, with stop and outlet

cocks and a graduated scale, and the whole of the receiver is easily protected from frost. The slate tank is sunk into the ground, the inside of the bottom is slightly coned with cement to the mouth of the outlet pipe, and the tank is filled with soil or earth to within 2 inches of the top. The soil is turfed over, kept level, and the

FIG. 3.



GENERAL PLAN OF THE GAUGES.

grass is occasionally cut; nothing is done to tighten the soil, and worms are sometimes seen. The water in the receiver never reaches the level of the bottom of the tank, the soil of which is underdrained.

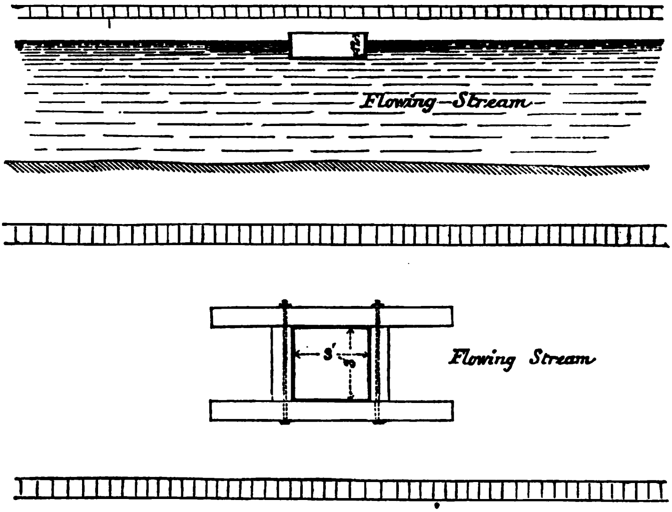
The "Dalton Gauge" has no overflow, and water has never been seen to accumulate on the surface of the earth or grass. It is intended that all rain that falls on it should soak in. The soil has once been taken out of the tank and put in again.

A rain gauge of equal superficial area, but only 1 foot deep, was fitted at the same time beside the "Dalton Gauge," and the two are under like conditions in all respects.

In the year 1860 another gauge, similar to the "Dalton," was established, and filled entirely with fine sand. This was with a view of getting at a definite maximum of percolation. The sand is also underdrained, and is therefore never in a state of stagnant saturation.

The observations from the above gauges did not afford all the knowledge required by the engineer to ascertain the amount of water available out of any known rainfall. They gave the rainfall, the percolation, and, by deduction, the evaporation, both from sand and from a surface of turf; but the evaporation from a

Fig. 4.



Box, or Floating Gauge (area 1 square yard), for the measurement of free evaporation from a surface of water.

water surface was wanted. This has been practically measured, since the end of 1859, in a similar gauge, 1 yard square and 1 foot deep, which has been kept afloat and partially immersed in a quiet part of a flowing stream (Fig. 4). The surface of the water within is always below that of the water without, and from 3 inches to 7 inches is found to be the best depth, this being ascertained periodically with a dip-stick. It is exposed to all weathers, and any addition or abstraction of water is duly recorded, none being made without necessity.

By combining together the observations in the ordinary closed rain gauge and those of the floating gauge, an absolute measure of

evaporation, from a water surface representing as nearly as can be the surface of a river, lake, or reservoir, is obtained.

The gauges stand at Lee Bridge, in the valley of the Lee, 6 miles north from, and $1\frac{1}{2}$ mile west of the meridian of, Greenwich. The surface is about 10 feet above Trinity high-water level. They are read at 9 A.M., and the records are booked to the day on which they are read.

By the use of the floating gauge the series of comparisons is greatly extended, and the relative proportion of evaporation from land and from water during varying seasons is conspicuously shown. It is not of course possible to affirm that the soil in the "Dalton" gauge is strictly representative. It was intended to resemble common Hertfordshire land, and was made up of soft earth with loam, gravel, and sand, all well mixed up beforehand and trodden in. Neither is it possible to assert that in every respect, and, at all times, the evaporation gauge has as accurate a relation to evaporation as rain gauges have to rain. Indeed, simple as they are, they have given occasion for a great variety of opinions.

The measurements in the floating gauge show directly a gain or a loss of water, and by combining the observations with those of the ordinary closed rain gauge the total evaporation is known. A rise of level in the water of the float is recorded as R, a fall as E. The formula for the use of the gauge is then total evaporation from water = R. G. (that is rain gauge) $\mp \frac{R}{E}$. A Table of total evaporation is thus obtained.

Comparison with the records of neighbouring rain gauges, as published by Mr. G. J. Symons, confirms the accuracy of the Lee Bridge returns. The average fall of rain at twelve stations in London for the seven years, 1864 to 1870, all agreeing closely together, was 24·486 inches; and at Lee Bridge, for the corresponding period, 23·934 inches.

Condensation of moisture on the surface of the sand gauge is of frequent occurrence. Only in three years out of the fourteen has the annual evaporation from water exceeded the rainfall, viz., in 1861, 1864, and 1868; in the year 1870 it was the same, and in the remaining years rain was in excess. The rise of water in a supposed tank open to rain and evaporation has been 71·5 inches in fourteen years. The percolation through ordinary ground has been 26·57 per cent. of the rainfall in twenty-two years, and the evaporation 73·42 per cent. of the rainfall. The evaporation from a surface of water has been 77·77 per cent. of the rainfall; still in 1861, 1864, and 1868, the evaporation exceeded the rainfall. In

such years the inability to store water, and the loss of store, are severely felt. The actual disappearance of a depth of 11·375 inches of water in seven months in 1868, of 10·625 inches in five months in 1870, of 9·375 inches in five months in 1864, and of 9·125 inches in seven months in 1861, from the surface of an inclosed area of water, by simple evaporation, is a feature that may disturb many calculations. A comparison of tables of evaporation and of rainfall is of great value to an engineer, as showing what can and what cannot be retained in an open receptacle subject to atmospheric influences. If evaporation were the purpose or the end sought, more effect could be attained by excluding the rain, if such could be done without hindering the access of sunshine and of air, but that is not the object. Clearly if an open vessel loses water it does so notwithstanding the rain. Evaporation is the difference between the amount of water in the covered and uncovered rain gauge if that in the latter gauge rises or gains, but the sum of the covered and uncovered gauges if that in the latter falls. If, therefore, evaporation is shown notwithstanding the inclusion of rain, it follows that the theoretical power of the air to evaporate is equal to the same amount inclusive of the rain gauge. The Author has not endeavoured to draw out the correspondence between humidity and evaporation. His object has been to get at a real result by a practical method, and so to design the apparatus that it may be capable of reproduction by other observers. With this view he has established another gauge, 3 feet square, and has floated it in a second 5 feet square. This method is within the reach of all inquirers, and independent of rivers or mill streams and their special difficulties.

Percolation.

The yield of springs, or the abundance of water in a river, where the river is fed from springs, will be found, from a comparison of the tables in the Appendix, to be dependent more closely on percolation through the soil than on the mere rainfall; indeed it will be found to correspond with percolation. For, whereas the variations in annual rainfall are as 2·33 to 1, being 37·166 inches in 1872 as compared with 15·891 inches in 1864, the annual percolation through ground varies as 3½ to 1, the greatest being 12·587 inches, the least 3·761 inches, in fourteen years. The percolation through sand varies as 7 to 4, being 30·050 inches in 1872, and 12·636 inches in 1864. The evaporation from a surface of water varied only from 26·933 inches to 17·332 inches, being nearly as 7 to 4½ in

fourteen years, but it is the intermitting character and its total absence in summer which are so specially characteristic of percolation. Great percolation supervenes on the thawing of snow, and the greatest is due to frequent thaws of small falls of snow. For many consecutive months there is often no percolation whatever, and the monthly range varies from 3·5 inches to nothing. Five times there has been no percolation for seven continuous months, and twice more for six months, and only in one year, 1860, has there been percolation every month.

A thoroughly underdrained soil, if sufficiently flat, would rarely produce any flood, that is, no water passing off by open water-courses. It would resemble the percolation gauge. The result of such underdraining on rivers would be to diminish floods, without lessening the annual discharge of water, and therefore to maintain the flow in dry seasons. Hollow draining does not diminish the perennial flow of rivers as much as improved superficial draining.

The Author believes 36 inches to be ample depth for a percolation gauge, and he is inclined to think that all water that passes a depth of 24 inches in the earth is safe from loss. It is, indeed, doubtful whether in the latitude and temperature of London capillarity has more than a negative action beyond 12 inches in depth. Probably on a moderately free soil the depth from which water is raised by capillarity is but a few inches, and in this may lie the difference in the healthiness of soils, the higher capillary power of a clay soil producing a constant summer exhalation. Whether the substrata underlying a clay soil are really deficient in moisture is a question not sufficiently determined; but the fact, if proved, would be an additional reason for hollow draining, speaking in the interest of agriculture or vegetation.

In order to bring the data into better practical use, the Author has reduced each of the tables into a twelvemonthly series, so as to show at the end of every quarter the result for the twelve months previous. By this means a series is produced with a continually uniform term, in which all the seasons take part. The effects of the four previous seasons, which always leave their mark on the earth, on vegetation, and on the climate, are thus continually imported into view. It does not appear needful to carry this form of table over a greater interval. It is possible that percolation, or the absence of it, at one period may have an influence extending over more than twelve months, but it is not habitually so. A wet winter will give abundant springs in the following autumn; but if that is followed by a dry winter, the latter will obliterate the effect of the previous wet winter.

The general conclusions from these records, and the most pro minent results observable, are then:—The magnitude of percolation through sand at all times—the smallness of percolation through earth on the whole—the consequent magnitude of evaporation—the entire absence of percolation in warm summer weather—the excess of evaporation from ground over evaporation from a surface of water in winter, and from a surface of water over evaporation from ground in summer—the small thickness of earth under which the water may be considered safe from loss—great variations observable in the twelvemonthly percolation, the maximum reaching ten to eleven times the minimum. Evaporation from earth approaches uniformity from year to year. It hardly reaches 2 to 1, seldom exceeds 25 inches or falls below 17 inches. Evaporation from water is the most uniform of all, the range only just exceeding 3 to 2, the maximum being 27 inches and the minimum 17 inches.

Districts more or less rainy have their special characteristics, known occasionally by popular observation and report, and more exactly where any system of recording has prevailed. Thanks to Mr. Symons' excellent and laborious records, the whole of Great Britain may now be mapped out into rain districts or zones; and if the rate of evaporation were equally well known, it would be possible to distinguish between dry and damp districts. The standard of evaporation and of percolation for any place will become hereafter as much a subject of study as that of rain.

Predictive meteorology is far removed from practical engineering, nevertheless the percolation gauge gives a most certain scale of the future state of springs. The delivery flow of water from springs in the autumn, and consequently the fulness of rivers so fed, is maintained by the rainfall of the previous winter. Summer percolation is nil; and rivers, except as influenced by the rain of the time being, will be short indeed, in September and October, if the percolation of rain has not been considerable in the previous December, January, or February. Intermittent springs are developed according to the previous percolation, and not simply according to the rainfall, with which they sometimes do not agree at all. Heavy rains in summer may afford no percolation, and a whole year may be considered wet, and yet not be one in which springs are fed. The quantity of water evaporated gives a scale of the capacity of the atmosphere for evaporation, and consequently of the degree of its humidity.

An artificial table for the Home Counties (Table I.) gives 18 inches of evaporation from the surface of the ground, out of 25

inches of rainfall; that is, 72 per cent., or 28 per cent. for percolation. The evaporation from a surface of water is at the same time 82 per cent., leaving 18 per cent. as the gain in rain. The percolation feed, therefore, in what is assumed to be a thoroughly-drained soil and subsoil, is greater than the direct feed on open water alone, as deduced from the balance of rain and evaporation.

After all, it may be argued that the Author's gauge is not the best, is not correct, is liable to accumulated and accidental heat—the bane of so many gauges; or that it is open to a double defect, of evaporation in excess in hot weather, and in defect in cold weather. Doubtless water in a shallow vessel is liable to become heated; but the surface of any water becomes heated, and the penetration varies with the depth, transparency, foulness, weediness, wind, waves, and movement, if a river, a mill stream, or a slow canal, or a ponded river. The Author is sanguine that his gauge is a good mean representative of all conditions. It was for some years in a more exposed situation, and appeared during a gale to be in so great danger of receiving the spray from waves dashing against the sides, that it was removed into a more quiet place. Certainly the less oscillation it suffers the better, as in an opposite way the wetting and drying of the inner surfaces must be a source of error, but a counter-action may be found in condensation at other times. Cases of negative evaporation in the floating gauge—that is, of increment above the rainfall—are not numerous; only three occurred in the fourteen years. But on the sand gauge it is frequent, owing to the great degree of cold which the sand evidently acquires. This induced cold causes condensation. Reverse evaporation, or more percolation than rainfall, has never appeared from the ground gauge.

This Paper is accompanied by a series of diagrams, from which Figs. 2, 3, and 4 have been compiled.

[APPENDIX.

APPENDIX.

TABLE I.—ARTIFICIAL TABLE of what may be expected as an AVERAGE YEAR.

—	Average Rain.	Average Sand.	Percolation Ground.	Average Box.
	Inches.	Inches.	Inches.	Inches.
January	2·000	1·875	1·250	2·500R
February	1·375	1·250	·750	1·875R
March	1·750	1·625	·750	1·125R
April	1·500	1·250	·250	·750R
May	2·250	1·875	·125	·250E
June	2·125	1·625	·125	2·750E
July	2·125	1·125	·125	2·250E
August	2·625	2·000	·125	1·500E
September	2·125	1·625	·250	1·000E
October	3·000	2·375	·750	1·500R
November	2·125	2·000	1·250	2·000R
December	2·000	1·375	1·250	2·500R
	25·000	20·000	7·000	4·500R

TABLE II.—LEE BRIDGE.

—	—	Rain.		Percolation.		—
		Quarter ending.	Year ending.	Quarter ending.	Year ending.	
		Inches.	Inches.	Inches.	Inches.	
1851	December	4·000	..	0·750	..	
1852	March	6·000	..	2·500	..	
	June	7·500	..	1·000	..	
	September	9·000	26·5	1·000	5·250	
	December	11·000	33·5	6·870	11·370	
1853	March	5·500	33·0	2·000	10·870	
	June	8·000	33·5	1·000	10·870	
	September	9·000	33·5	1·000	10·870	
	December	6·000	28·5	1·500	5·500	
1854	March	3·500	26·5	0·500	4·000	
	June	5·000	23·5	..	3·000	
	September	4·000	18·5	..	2·000	
	December	5·000	17·5	0·750	1·250	
1855	March	4·021	18·321	0·674	1·424	Very dry.
	June	1·917	15·238	0·030	1·454	
	September	8·776	19·814	..	1·454	
	December	10·000	24·714	2·000	2·704	
1856	March	4·812	25·505	3·725	5·755	
	June	7·021	30·609	0·136	5·861	
	September	6·937	28·770	..	5·861	
	December	5·042	23·812	0·999	4·860	
1857	March	5·105	24·105	2·590	3·725	
	June	5·667	22·751	..	3·589	
	September	9·710	25·524	1·925	5·514	
	December	8·145	28·627	3·825	8·340	
1858	March	4·605	28·127	1·950	7·700	
	June	7·419	29·879	1·225	8·925	
	September	6·332	26·501	0·175	7·175	
	December	5·543	23·899	0·150	3·500	
1859	March	3 311	22·605	0·750	2·300	
	June	7·687	22·873	0·500	1·575	
	September	7·895	24·436	0·100	1·500	Very dry.
	December	8·874	27·767	6·036	7·387	

TABLE II. (*continued.*)

—	—	Rain.		Percolation.		—
		Quarter ending.	Year ending.	Quarter ending.	Year ending.	
		Inches.	Inches.	Inches.	Inches.	
1860	March . .	5·227	29·683	3·175	9·812	
	June . .	10·520	32·516	2·387	11·699	
	September	9·312	33·933	1·837	13·436	
	December.	7·499	32·558	3·362	10·761	
1861	March . .	6·266	33·597	2·762	10·348	
	June . .	4·141	27·218	0·187	8·148	
	September	5·374	23·280	..	6·311	
	December.	7·852	23·633	2·762	5·711	
1862	March. .	6·645	24·012	3·437	6·386	
	June . .	7·813	27·684	1·649	7·848	
	September	5·332	27·642	..	7·848	
	December.	6·791	26·581	3·462	8·549	
1863	March. .	4·062	23·998	2·387	7·498	
	June . .	5·270	21·455	..	5·849	
	September	5·206	21·329	..	5·849	
	December.	5·228	19·766	1·374	3·761	
1864	March .	4·728	20·432	2·862	4·236	
	June . .	3·770	18·932	0·062	4·298	
	September	3·936	17·662	..	4·298	Very dry.
	December.	3·457	15·891	0·899	3·824	
1865	March .	7·145	18·308	5·425	6·386	
	June . .	5·083	19·620	0·025	6·349	
	September	7·896	23·580	0·837	7·186	
	December.	9·124	29·248	4·862	11·150	
1866	March. .	9·291	31·394	7·575	13·299	
	June . .	7·895	34·206	1·425	14·699	
	September	7·855	34·165	..	13·862	
	December.	6·655	31·697	3·587	12·587	
1867	March. .	8·333	30·738	4·287	9·299	
	June . .	5·749	28·593	0·087	7·962	
	September	8·729	29·467	..	7·962	
	December.	4·623	27·436	0·787	5·162	
1868	March. .	6·437	25·538	3·812	4·686	
	June . .	3·662	23·451	0·037	4·636	
	September	4·166	18·888	..	4·636	Very dry.
	December.	9·041	23·308	3·262	7·112	
1869	March. .	7·000	23·868	5·325	8·624	
	June . .	5·395	25·601	0·162	8·749	
	September	4·354	25·789	..	8·749	
	December.	7·812	24·562	2·562	8·050	
1870	March. .	4·854	22·415	3·262	5·986	
	June . .	1·604	18·624	0·050	5·874	
	September	5·354	19·624	..	5·874	
	December.	8·583	20·395	3·912	7·225	
1871	March. .	5·458	20·999	3·800	7·762	
	June . .	6·062	25·457	0·375	8·087	
	September	8·916	29·019	0·075	8·162	
	December.	3·645	24·083	1·937	6·188	
1872	March. .	8·208	26·831	4·862	7·247	
	June . .	7·624	28·393	1·063	7·947	
	September	7·020	26·497	..	7·872	
	December.	14·312	37·166	6·100	12·025	
1873	March. .	6·020	34·976	2·937	10·009	
	June . .	5·062	32·414	..	9·037	
	September	6·875	32·269	..	9·037	
	December.	5·812	23·770	1·112	4·050	

TABLE III.

		Average inches.
Rainfall	22 years.	25·837
Percolation ground	22 „	6·866
Evaporation ground	22 „	18·970
Rainfall	19 „	25·732
Percolation ground	19 „	6·996
Evaporation ground	19 „	18·735
Rainfall	14 „	25·721
Percolation ground	14 „	7·582
Evaporation ground	14 „	18·138
Evaporation ground for same years as water	14 „	18·138
Evaporation water	14 „	20·613
Evaporation sand	14 „	4·313
		25·721
Excess of rain over evaporation from water	14 „	20·613
		5·108
		20·613
Excess of evaporation from water over evaporation from ground	14 „	18·138
		2·475

TABLE IV.

—	Rain.	Perco. Ground.	Evap. Ground.	Perco. Sand.	Evap. Sand.	Evap. Water.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
1852	33·500	11·370	22·130	..	..	..
1853	28·500	5·500	23·000	..	..	..
1854	17·500	1·250	16·250	..	..	..
1855	24·714	2·704	22·010	..	..	..
1856	23·812	4·860	18·952	..	..	..
1857	28·627	8·340	20·287	..	..	..
1858	23·899	3·500	20·399	..	..	..
1859	27·767	7·387	20·380	..	..	..
1860	32·558	10·761	21·797	23·456	9·102	21·058
1861	23·633	5·711	17·921	16·360	7·273	25·008
1862	26·581	8·549	18·032	21·178	5·402	17·332
1863	19·766	3·761	16·005	16·411	3·353	18·266
1864	15·891	3·824	12·067	12·636	3·255	18·640
1865	29·248	11·150	18·098	27·823	1·425	20·124
1866	31·697	12·587	19·110	28·112	3·585	18·821
1867	27·436	5·162	22·274	22·424	5·011	20·061
1868	23·308	7·112	16·196	20·200	3·108	26·933
1869	24·562	8·050	16·512	22·137	2·425	19·062
1870	20·395	7·225	13·170	18·699	1·696	20·396
1871	24·083	6·188	17·895	20·087	3·956	19·583
1872	37·166	12·025	25·141	30·050	7·116	22·916
1873	23·770	4·050	19·720	20·120	3·650	20·395
22)	568·413	151·063	417·345			
	25·837	6·866	18·970			
19)	488·913	132·943	355·965			
	25·732	6·996	18·735			
14)	360·094	106·152	253·937	299·693	60·394	288·594
	25·721	7·582	18·138	21·406	4·313	20·613

TABLE V.—BALANCE of RAIN and EVAPORATION (Open Box). Single Months, showing an Extreme Descent of a Water Surface.

		Inches.
August,	1861	3·125E
July,	1863	3·125E
July,	1864	3·375E
June,	1868	4·000E
July,	1868	4·500E
June,	1870	3·250E

TABLE VI.—TOTAL EVAPORATION from WATER (R. G. + E.). Same Months as above with some added Extreme Cases. Rainfall as above plus Descent of Surface.

		Inches.
May,	1861	3·250
June,	1861	3·058
July,	1861	4·145
August,	1861	3·875
July,	1863	3·895
June,	1864	3·333
July,	1864	3·604
June,	1865	3·229
August,	1865	3·979
July,	1866	3·937
June,	1867	3·500
May,	1868	3·312
June,	1868	4·600
July,	1868	4·854 (max.)
July,	1869	3·000
May,	1870	3·187
June,	1870	3·750
July,	1870	3·187
August,	1870	3·166
August,	1871	3·041
June,	1872	3·166
July,	1872	3·020
May,	1873	3·062
July,	1873	3·687

TABLE VII.—GREATEST DESCENT of a WATER SURFACE in CONTINUOUS PERIODS.

		Inches.	
1861	3 months	5·625E.	
	6 „	9·000E.	
	7 „	9·125E.	
1864	3 „	7·000E.	
	5 „	9·375E.	
1868	3 „	10·500E.	Max. 3 months.
	6 „	11·250E.	Max. 6 „
	7 „	11·375E.	
1870	3 „	8·250E.	
	5 „	10·625E.	Max. 5 „

TABLE VIII.

—	Total evaporation from water		= Rain. R. G.	+ R. or E. E.	—
	Inches.	Months.	Inches.	Inches.	
1861	11·078	3	5·453	5·625E	June, July, August.
	18·515	6	9·515	9·000E	Apr., May, June, July, Aug., Sept.
	19·806	7	10·681	9·125E	Ditto, and October.
1864	9·624	3	2·624	7·000E	June, July, August.
	14·311	5	4·936	9·375E	April, May, June, July, August.
1868	12·766	3	2·266	10·500E	May, June, July.
	19·079	6	7·829	11·250E	Apr., May, June, July, Aug., Sept.
	20·849	7	9·474	11·375E	March, and same.
1870	10·125	3	1·875	8·250E	May, June, July.
	15·583	5	4·958	10·625E	April, May, June, July, August.

TABLE IX.—ACCUMULATION of RAIN.

	Inches.
End of 1859 . . .	·0
„ 1860 . . .	11·500
„ 1861 . . .	10·125
„ 1862 . . .	19·375
„ 1863 . . .	20·875
„ 1864 . . .	18·125
„ 1865 . . .	27·250
„ 1866 . . .	40·125
„ 1867 . . .	47·500
„ 1868 . . .	43·875
„ 1869 . . .	49·375
„ 1870 . . .	49·375
„ 1871 . . .	53·875
„ 1872 . . .	68·125
„ 1873 . . .	71·500

So that in each of the years in which the great losses occurred there was a loss on the whole year thus:—

	Inches.
1861	1·375E.
1864	2·750E.
1868	3·625E.
1870	R = E.

TABLE X.—PROPORTION of RAIN to PERCOLATION.

	Rain. —		Percolation. —		
	Inches.		Inches.		
12 months . . .	25·837	. . . . . .	6·866	average of 22 years.	
Previous 12 months—	17·500	. . . . .	1·250	min. Dec.	1854
	24·436	max. dis.[1] > .	1·500	Sept.	1859
	34·206	max. . . .	14·699	June	1866
	34·165	2nd max. . .	13·862	Sept.	1866
	33·933	3rd max. . .	13·436	Sept.	1860
	18·308	min. dis.[1] > .	6·386	March	1865
	29·248	„ or . .	11·150	Dec.	1865
	31·394	„ „ . .	13·299	March	1866
	34·206	„ „ . .	14·699	June	1866
	34·165	„ „ . .	13·862	Sept.	1866
	31·697	„ „ . .	12·587	Dec.	1866
	15·891	2nd min. . .	3·824	Dec.	1864
	15·238	min. . . .	1·454	June	1855
	25·837	averages . .	6·866	22 yrs. average.	
Actual . . .	23·633	{ nearest to }	5·711	. . .	1861
	26·581	{ the averages }	8·549	. . .	1862

[1] Disproportion.

Table XI.—Comparative Evaporation from Ground and Water.

	Evap. Ground—		Evap. Water—		
	18·970	. . . . . .	—		22 yrs. average.
	18·138	. . . . . .	20·613		14 yrs. average.
In the 22 years	25·141	max. . . .	—	. . .	1872
	23·000	2nd max. . .	—	. . .	1853
	22·274	3rd max. . .	—	. . .	1867
	22·010	4th max. . .	—	. . .	1855
	12·067	min. . . .	—	. . .	1864
	13·170	2nd min. . .	—	. . .	1870
In the 14 years	25·141	max. . . .	22·916	. . .	1872
	22·274	2nd max. . .	20·061	. . .	1867
	16·196	. . . . . .	26·933	max. .	1868
	12·067	min. . . .	18·640	. . .	1864
	18·032	. . . . . .	17·332	min. . .	1862
	22·274	max. dis. > .	20·061	. . .	1867
	16·196	< max. dis. .	26·933	. . .	1868
	17·921	next nearest .	25·008	. . .	1861
	12·067	to equality . .	18·640	. . .	1864

Table XII.—Summary of Fourteen Years.[1]

Year.	Rain.	Percolation.		Evaporation.				Year.
		Ground.	Sand.	Ground.	Sand.	Box.	Water.	
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	
1860	32·558	10·761	23·456	21·797	9·102	R 11·500	21·058	1860
1861	23·633	5·711	16·360	17·921	7·273	E 1·375	25·008	1861
1862	26·581	8·549	21·178	18·031	5·402	R 9·250	17·332	1862
1863	19·766	3·761	16·411	16·004	3·353	R 1·500	18·266	1863
1864	15·891	3·824	12·636	12·067	3·255	E 2·750	18·640	1864
1865	29·248	11·150	27·823	18·098	1·425	R 9·125	20·124	1865
1866	31·697	12·587	28·112	19·110	3·585	R 12·875	18·821	1866
1867	27·436	5·162	22·424	22·274	5·011	R 7·375	20·061	1867
1868	23·308	7·112	20·200	16·196	3·108	E 3·625	26·933	1868
1869	24·562	8·050	22·138	16·512	2·425	R 5·500	19·062	1869
1870	20·395	7·225	18·700	13·170	1·696	R = E	20·396	1870
1871	24·083	6·188	20·087	17·895	3·996	R 4·500	19·583	1871
1872	37·166	12·025	30·050	25·141	7·116	R 14·250	22·916	1872
1873	23·770	4·050	20·120	19·721	3·650	R 3·375	20·395	1873

[1] Any discrepancies that may be noticed in the following tables are due to their having been originally carried out to four places of decimals.—C. G.

TABLE XIII.

1860.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·520	..	..	1·600	..	..	1·800	..	..	0·920	..	..	0·720	..	..	R 2·111	..	..	0·409	..	..
Feb.	1·187	3·707	..	0·725	2·325	..	0·925	2·725	..	0·462	1·382	..	0·262	0·982	..	R 0·788	2·899	..	0·409	0·818	..
Mar.	1·520	5·227	5·227	0·850	3·175	3·175	1·120	3·845	3·845	0·670	2·052	2·052	0·400	1·382	1·382	R 1·111	R 4·000	R 4·000	0·409	1·227	1·227
Apr.	1·458	6·685	..	0·162	3·337	..	0·975	4·820	..	1·296	3·348	..	0·483	1·865	..	E 0·750	R 3·250	..	2·208	3·435	..
May	3·500	10·185	..	0·575	3·912	..	2·475	7·295	..	2·925	6·273	..	1·025	2·890	..	R 0·875	R 4·125	..	2·625	6·060	..
June	5·562	15·747	10·520	1·650	5·562	2·387	3·975	11·270	7·425	3·912	10·185	8·133	1·587	4·477	3·095	R 1·750	R 5·875	R 1·875	3·812	9·872	8·645
July	1·875	17·622	..	0·150	5·712	..	1·587	12·857	..	1·725	11·910	..	0·288	4·765	..	E 1·625	R 4·250	..	3·500	13·372	..
Aug.	4·354	21·976	..	0·762	6·474	..	3·450	16·307	..	3·592	15·502	..	0·904	5·669	..	R 1·375	R 5·625	..	2·979	16·351	..
Sept.	3·083	25·059	9·312	0·925	7·399	1·837	2·475	18·782	7·512	2·158	17·660	7·475	0·608	6·277	1·800	R 1·375	R 7·000	R 1·125	1·708	18·059	8·187
Oct.	1·562	26·621	..	0·625	8·024	..	1·587	20·369	..	0·937	18·597	..	Rev 0·025	6·252	..	R 0·375	R 7·375	..	1·187	19·246	..

Table XIV.

1861.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2.267	..	..	0.975	..	..	1.800	..	..	1.292	..	..	0.467	..	..	R 1.375	..	..	0.892	..	..
Feb.	1.520	3.787	..	0.762	1.737	..	1.037	2.837	..	0.758	2.050	..	0.483	0.950	..	R 1.375	R 2.750	..	0.145	1.037	..
Mar.	2.479	6.266	6.266	1.025	2.762	2.762	1.950	4.787	4.787	1.454	3.504	3.504	0.529	1.479	1.479	R 0.750	R 3.500	R 3.500	1.729	2.766	2.766
Apr.	1.083	7.349	..	0.187	2.949	..	0.550	5.337	..	0.895	4.399	..	0.533	2.012	..	E 1.375	R 2.125	..	2.458	5.224	..
May	1.125	8.474	..	..	2.949	..	1.187	6.524	..	1.125	5.524	..	Rev 0.062	1.950	..	E 2.125	=	..	3.250	8.474	..
June	1.933	10.407	4.141	..	2.949	0.187	0.837	7.361	2.574	1.933	7.457	3.953	1.096	3.046	1.567	E 1.125	E 1.125	E 4.625	3.058	11.532	8.766
July	2.770	13.177	..	..	2.949	..	1.225	8.586	..	2.770	10.227	..	1.545	4.591	..	E 1.375	E 2.500	..	4.145	15.677	..
Aug.	0.750	13.927	..	..	2.949	..	0.500	9.086	..	0.750	10.977	..	0.250	4.841	..	E 3.125	E 5.625	..	3.875	19.552	..
Sept.	1.854	15.781	5.374	..	2.949	..	0.850	9.936	2.575	1.854	12.831	5.374	1.004	5.845	2.799	R 0.125	E 5.500	E 4.375	1.729	21.281	9.749
Oct.	1.166	16.947	..	..	2.949	..	0.900	10.836	..	1.166	13.997	..	0.266	6.111	..	E 0.125	E 5.625	..	1.291	22.572	..
Nov.	4.895	21.842	..	1.400	4.349	..	3.812	14.648	..	3.495	47.492	..	1.083	7.194	..	R 3.500	E 2.125	..	1.395	23.967	..
Dec.	1.791	23.633	7.852	1.362	5.711	2.762	1.712	16.360	6.424	0.429	17.921	5.090	0.079	7.273	1.428	R 0.750	E 1.375	R 4.125	1.041	25.008	3.727
			23.633			5.711			16.360			17.921			7.273			E 1.375			25.008

TABLE XV.

1862.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·104	..	..	0·800	..	..	1·400	..	..	1·304	..	..	0·704	..	..	R 2·000	..	..	0·104	..	..
Feb.	0·541	2·645	..	0·375	1·175	..	0·725	2·125	..	0·166	1·470	..	*Rev* 0·184	0·520	..	E 0·375	R 1·625	..	0·916	1·020	..
Mar.	4·000	6·645	6·645	2·262	3·437	3·437	3·075	5·200	5·200	1·737	3·207	3·207	0·925	1·445	1·445	R 3·125	R 4·750	R 4·750	0·875	1·895	1·895
Apr.	2·604	9·249	..	1·362	4·799	..	1·900	7·100	..	1·241	4·449	..	0·704	2·149	..	R 0·500	R 5·250	..	2·105	4·000	..
May	3·229	12·478	..	0·287	5·087	..	2·700	9·800	..	2·941	7·390	..	0·529	2·678	..	R 1·000	R 6·250	..	2·229	6·229	..
June	1·980	14·458	7·813	..	5·087	1·649	1·437	11·237	6·037	1·980	9·370	6·163	0·542	3·220	1·775	E 0·750	R 5·500	R 0·750	2·730	8·959	7·064
July	1·666	16·124	..	..	5·087	..	0·975	12·212	..	1·666	11·036	..	0·691	3·911	..	E 1·125	R 4·375	..	2·791	11·750	..
Aug.	2·125	18·249	..	..	5·087	..	2·000	14·212	..	2·125	13·161	..	0·125	4·036	..	E 0·125	R 4·250	..	2·250	14·000	..
Sept.	1·541	19·790	5·332	..	5·087	..	0·800	15·012	3·775	1·541	14·702	5·332	0·741	4·777	1·557	R 0·125	R 4·375	E 1·125	1·416	15·416	6·457
Oct.	3·875	23·665	..	1·487	6·574	..	3·512	18·524	..	2·387	17·089	..	0·362	5·140	..	R 2·625	R 7·000	..	1·250	16·666	..

TABLE XVI.

1863.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·729	..	..	2·050	..	..	2·675	..	..	0·679	..	..	0·054	..	..	R 1·625	..	..	1·104	..	..
Feb.	0·625	3·354	..	0·262	2·312	..	0·725	3·400	..	0·362	1·041	..	Rev 0·100	..	..	R 0·375	R 2·000	..	0·250	1·354	..
Mar.	0·708	4·062	4·062	0·075	2·387	2·387	0·712	4·112	4·112	0·633	1·674	1·674	Rev 0·004	Rev 0·050	Rev 0·050	R = E	R 2·000	R 2·000	0·708	2·062	2·062
Apr.	0·416	4·478	..	..	2·387	..	0·275	4·387	..	0·416	2·090	..	0·141	0·091	..	E 2·000	..	..	2·416	4·478	..
May	1·125	5·603	..	..	2·387	..	0·775	5·162	..	1·125	3·215	..	0·350	0·441	..	E 1·250	E 1·250	..	2·375	6·853	..
June	3·729	9·332	5·270	..	2·387	..	2·237	7·399	3·287	3·729	6·944	5·270	1·491	1·932	1·982	R 1·000	E 0·250	E 2·250	2·729	9·582	7·520
July	0·770	10·102	..	..	2·387	..	0·700	8·099	..	0·770	7·714	..	0·070	2·002	..	E 3·125	E 3·375	..	3·895	13·477	..
Aug.	1·291	11·393	..	..	2·387	..	0·975	9·074	..	1·291	9·005	..	0·316	2·318	..	E 1·000	E 4·375	..	2·291	15·768	..
Sept.	3·145	14·538	5·206	..	2·387	..	2·625	11·699	4·300	3·145	12·150	5·206	0·520	2·838	0·906	R 2·000	E 2·375	E 2·125	1·145	16·913	7·331
Oct.	2·208	16·746	..	..	2·387	..	1·712	13·411	..	2·208	14·358	..	0·495	3·333	..	R 1·250	E 1·125	..	0·958	17·871	..
Nov.	1·937	18·683	..	0·687	3·074	..	1·925	15·336	..	1·250	15·608	..	0·012	3·345	..	R 1·875	R 0·750	..	0·062	17·933	..
Dec.	1·083	19·766	5·228	0·687	3·761	1·374	1·075	16·411	4·712	0·396	16·004	3·854	0·008	3·353	0·515	R 0·750	R 1·500	R 3·875	0·333	18·266	1·353
			19·766			3·761			16·411			16·004			3·353			R 1·500			18·266

TABLE XVII.

1864.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	1·083	..	..	0·637	..	..	0·850	..	..	0·446	..	..	0·233	..	..	R 0·875	..	..	0·208	..	..
Feb.	0·937	2·020	..	0·387	1·025	..	0·637	1·487	..	0·550	0·996	..	0·300	0·533	..	R 0·750	1·625	..	0·187	0·395	..
Mar.	2·708	4·728	4·728	1·837	2·862	2·862	2·437	3·924	3·924	0·870	1·866	1·866	0·271	0·804	0·804	R 1·875	R 3·500	R 3·500	0·833	1·228	1·228
Apr.	0·854	5·582	..	0·062	2·925	..	0·575	4·499	..	0·791	2·757	..	0·279	1·083	..	E 1·500	R 2·000	..	2·354	3·582	..
May	1·458	7·040	..	..	2·925	..	1·125	5·624	..	1·458	4·115	..	0·333	1·416	..	E 0·875	R 1·125	..	2·333	5·915	..
June	1·458	8·498	3·770	..	2·925	0·062	0·750	6·374	2·450	1·458	5·574	3·708	0·708	2·124	1·320	E 1·875	E 0·750	E 4·250	3·333	9·248	8·020
July	0·229	8·727	..	..	2·925	..	0·212	6·586	..	0·229	5·803	..	0·016	2·140	..	E 3·375	R 4·125	..	3·604	12·852	..
Aug.	0·937	9·664	..	..	2·925	..	0·500	7·086	..	0·937	6·740	..	0·437	2·578	..	E 1·750	E 5·875	..	2·687	15·539	..
Sept.	2·770	12·434	3·936	..	2·925	..	2·275	9·361	2·987	2·770	9·510	3·936	0·495	3·073	0·949	R 0·875	E 5·000	E 4·250	1·895	17·434	8·186
Oct.	0·833	13·267	..	..	2·925	..	0·800	10·161	..	0·833	10·343	..	0·033	3·106	..	E 0·250	E 5·250	..	1·082	18·516	..
Nov.	1·854	15·121	..	0·387	3·312	..	1·725	11·886	..	1·466	11·809	..	0·129	3·285	..	R 2·125	E 3·125	..	*Rev* 0·271	18·245	..
Dec.	0·770	15·891	3·457	0·512	3·824	0·899	0·750	12·636	3·275	0·258	12·067	2·557	0·020	3·255	0·182	R 0·875	E 2·750	R 2·250	0·395	18·640	1·206
			15·891			3·824			12·636			12·067			8·255			R 2·750			18·640

TABLE XVIII.

1865.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	3·333	..	..	2·300	..	..	2·925	..	..	1·033	..	..	0·408	..	..	R 3·375	..	..	Rev 0·042	..	..
Feb.	2·812	6·145	..	2·450	4·750	..	2·975	5·900	..	0·362	1·395	..	Rev 0·163	0·245	..	R 1·750	R 5·125	..	1·062	1·020	..
Mar.	1·000	7·145	7·145	0·675	5·425	5·425	1·100	7·000	7·000	0·325	1·720	1·720	Rev 0·100	0·145	0·145	R 0·250	R 5·375	R 5·375	0·750	1·770	1·770
Apr.	0·395	7·541	..	0·025	5·450	..	0·512	7·512	..	0·370	2·090	..	Rev 0·116	0·029	..	E 1·875	R 3·500	..	2·270	4·041	..
May	3·333	10·874	..	..	5·450	..	2·837	10·349	..	3·333	5·423	..	0·495	0·524	..	R 0·625	R 4·125	..	2·708	6·749	..
June	1·354	12·228	5·083	..	5·450	0·025	1·225	11·574	4·574	1·354	6·777	5·057	0·129	0·653	0·508	E 1·875	R 2·250	E 3·125	3·229	9·978	8·208
July	2·042	14·270	..	..	5·450	..	1·812	13·386	..	2·042	8·819	..	0·230	0·883	..	0·875	R 1·375	..	2·917	12·895	..
Aug.	5·479	19·749	..	0·825	6·275	..	4·862	18·248	..	4·654	13·473	..	0·616	1·499	..	R 1·500	R 2·875	..	3·979	16·874	..
Sept.	0·375	20·124	7·896	0·012	6·287	0·837	0·512	18·761	7·187	0·363	13·837	7·059	Rev 0·137	1·362	0·709	E 1·375	R 1·500	E 0·750	1·750	18·624	8·646
Oct.	5·812	25·936	..	2·375	8·662	..	5·312	24·073	..	3·437	17·274	..	0·500	1·862	..	R 5·250	R 6·750	..	0·562	19·187	..
Nov.	2·000	27·936	..	1·862	10·525	..	2·587	26·660	..	0·137	17·411	..	Rev 0·587	1·275	..	R 1·500	R 8·250	..	0·500	19·687	..
Dec.	1·312	29·248	9·124	0·625	11·150	4·862	1·162	27·823	9·062	0·687	18·098	4·262	0·150	1·425	0·063	R 0·875	R 9·125	R 7·625	0·437	20·124	1·500
			29·248			11·150			27·823			18·098			1·425			R 9·125			20·124

TABLE XIX.

1866.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	3·791	..	..	3·475	..	..	4·462	..	..	0·316	..	..	*Rev* 0·670	..	..	R 3·500	..	..	0·291	..	..
Feb.	4·229	8·020	..	3·350	6·825	..	3·887	8·349	..	0·879	1·195	..	0·341	*Rev* 0·329	..	R 3·375	6·875	..	0·854	1·145	..
Mar.	1·270	9·291	9·291	0·750	7·575	7·575	1·275	9·625	9·625	0·520	1·716	1·716	*Rev* 0·004	*Rev* 0·333	*Rev* 0·333	R 0·750	R 7·625	R 7·625	0·520	1·666	1·666
Apr.	2·395	11·686	..	0·937	8·512	..	1·962	11·586	..	1·458	3·174	..	0·433	0·100	..	R 0·125	R 7·750	..	2·270	3·936	..
May	1·354	13·040	..	..	8·512	..	1·175	12·761	..	1·354	4·528	..	0·179	0·279	..	R 1·250	R 6·500	..	2·604	6·540	..
June	4·145	17·186	7·895	0·487	9·000	1·425	3·537	16·300	6·675	3·658	8·186	6·470	0·608	0·887	1·220	R 1·750	R 8·250	R 0·625	2·395	8·936	7·270
July	1·687	18·874	..	..	9·000	..	1·312	17·612	..	1·687	9·873	..	0·375	1·262	..	R 2·250	R 6·000	..	3·937	12·873	..
Aug.	2·687	21·561	..	..	9·000	..	1·487	19·100	..	2·687	12·561	..	1·200	2·462	..	R 0·250	R 6·250	..	2·437	15·311	..
Sept.	3·480	25·041	7·855	..	9·000	..	2·700	21·800	5·500	3·480	16·041	7·855	0·780	3·242	2·355	R 1·875	R 8·125	R 0·125	1·605	16·916	7·980
Oct.	2·312	27·353	..	0·725	9·725	..	2·250	24·050	..	1·587	17·628	..	0·062	3·304	..	R 1·500	R 9·625	..	0·812	17·728	..
Nov.	1·739	29·092	..	0·975	10·700	..	1·687	25·737	..	0·764	18·392	..	0·052	3·355	..	R 1·125	R 10·750	..	0·614	18·342	..
Dec.	2·604	31·697	6·655	1·887	12·587	3·587	2·375	28·112	6·312	0·716	19·110	3·068	0·229	3·584	0·343	R 2·125	R 12·875	4·750	0·479	18·821	1·905
			31·697			12·587			28·112			19·110			3·585			R 12·875			18·821

1867.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	4·000	..	..	1·725	..	..	2·712	..	..	2·275	..	..	1·287	..	..	R 2·375	..	..	1·625	..	..
Feb.	1·937	5·937	..	1·475	3·200	..	2·075	4·787	..	0·462	2·737	..	*Rev* 0·137	1·150	..	R 0·750	R 3·125	..	1·187	2·812	..
Mar.	2·395	8·333	8·333	1·087	4·287	4·287	1·812	6·600	6·600	1·308	4·045	4·045	0·583	1·733	1·733	R 1·250	R 4·375	R 4·375	1·145	3·958	3·958
Apr.	1·979	10·312	..	0·087	4·375	..	1·437	8·038	..	1·891	5·937	..	0·541	2·274	..	R 0·375	R 4·750	..	1·604	5·562	..
May	2·520	12·833	..	..	4·375	..	1·862	9·900	..	2·520	8·458	..	0·658	2·933	..	E 0·125	R 4·625	..	2·645	8·208	..
June	1·250	14·083	5·749	..	4·375	0·087	1·112	11·012	4·412	1·250	9·708	5·662	0·137	3·070	1·337	E 2·250	R 2·375	E 2·000	3·500	11·708	7·749
July	4·541	18·624	..	..	4·375	..	3·575	14·587	..	4·541	14·249	..	0·966	4·037	..	R 1·875	R 4·250	..	2·666	14·374	..
Aug.	2·104	20·728	..	..	4·375	..	2·000	16·587	..	2·104	16·353	..	0·104	4·141	..	R=E	R 4·250	..	2·104	16·478	..
Sept.	2·083	22·812	8·729	..	4·375	..	1·550	18·137	7·125	2·083	18·437	8·729	0·533	4·674	1·604	R 0·250	R 4·500	R 2·125	1·833	18·312	6·604
Oct.	1·937	24·749	..	..	4·375	..	1·400	19·537	..	1·937	20·374	..	0·537	5·211	..	R 1·187	R 5·687	..	0·750	19·062	..
Nov.	0·145	24·895	..	..	4·375	..	0·475	20·012	..	0·145	20·520	..	*Rev* 0·329	4·882	..	E 0·062	R 5·625	..	0·208	19·270	..
Dec.	2·541	27·436	4·623	0·787	5·162	0·787	2·412	22·424	4·287	1·754	22·274	3·836	0·129	5·011	0·337	R 1·750	R 7·375	R 2·875	0·791	20·061	1·749
			27·436			5·162			22·424			22·274			5·011			R 7·375			20·061

TABLE XXI.

1868.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	3·958	..	..	3·325	..	..	4·075	..	..	0·633	..	..	Rev 0·117	..	..	R 3·250	..	..	0·708	..	..
Feb.	0·833	4·791	..	0·413	3·738	..	0·788	4·863	..	0·421	1·054	..	0·046	Rev 0·071	..	R 0·125	R 3·375	..	0·708	1·416	..
Mar.	1·646	6·437	6·437	0·075	3·813	3·813	0·937	5·800	5·800	1·571	2·625	2·625	0·708	0·637	0·637	E 0·125	R 3·250	R 3·250	1·771	3·187	3·187
Apr.	1·750	8·187	..	0·037	3·850	..	1·463	7·263	..	1·712	4·337	..	0·288	0·925	..	E 0·125	R 3·125	..	1·875	5·062	..
May	1·313	9·500	..	..	3·850	..	0·925	8·188	..	1·313	5·650	..	0·387	1·312	..	E 2·000	R 1·125	..	3·313	8·875	..
June	0·600	10·100	3·663	..	3·850	0·037	0·725	8·913	3·113	0·600	6·250	3·625	Rev 0·125	1·187	0·550	E 4·000	E 3·875	E 6·125	4·600	12·975	9·788
July	0·354	10·454	..	..	3·850	..	0·200	9·113	..	0·354	6·604	..	0·154	1·341	..	E 4·500	E 7·375	..	4·854	17·829	..
Aug.	2·562	13·016	..	..	3·850	..	1·712	10·825	..	2·563	9·167	..	0·850	2·191	..	E 0·375	E 7·750	..	2·937	20·766	..
Sept.	1·250	14·266	4·166	..	3·850	..	0·350	11·175	2·262	1·250	10·417	4·167	0·900	3·091	1·904	E 0·250	E 8·000	E 5·125	1·500	22·266	9·291
Oct.	2·667	16·933	..	..	3·[illegible]	..	2·950	14·125	..	2·666	13·083	..	Rev 0·283	2·808	..	R 1·500	E 6·500	..	1·167	23·433	..
Nov.	1·000	17·933	..	..	3·850	..	1·138	15·263	..	1·000	14·083	..	Rev 0·138	2·670	..	E 1·625	E 8·125	..	2·625	26·058	..
Dec.	5·375	23·308	9·042	3·262	7·112	3·262	4·937	20·000	9·025	2·113	16·196	5·779	0·438	3·108	0·017	R 4·500	E 3·625	R 4·375	0·875	26·933	4·667
			23·308			7·112			20·200			16·196			3·108			E 3·625			26·933

1869.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·959	..	..	2·500	..	..	3·162	..	..	0·458	..	..	*Rev* 0·204	..	..	R 2·250	..	..	0·708	..	..
Feb.	2·583	5·542	..	2·100	4·600	..	2·788	5·950	..	0·483	0·941	..	*Rev* 0·204	*Rev* 0·408	..	R 1·500	R 3·750	..	1·083	1·791	..
Mar.	1·458	7·000	7·000	0·725	5·325	5·325	1·412	7·362	7·362	0·733	1·674	1·674	0·046	*Rev* 0·362	*Rev* 0·362	R 0·500	R 4·250	R 4·250	0·959	2·750	2·750
Apr.	1·167	8·167	..	0·050	5·375	..	1·063	8·425	..	1·117	2·791	..	0·104	*Rev* 0·258	..	E 0·625	R 3·625	..	1·792	4·542	..
May	3·250	11·417	..	0·112	5·487	..	2·750	11·175	..	3·138	5·929	..	0·500	0·242	..	R 0·875	R 4·500	..	2·375	6·917	..
June	0·979	12·396	5·396	..	5·487	0·162	0·862	12·037	4·675	0·979	6·908	5·234	0·116	0·358	0·720	E 2·000	R 2·500	E 1·750	2·979	9·896	7·146
July	0·500	12·896	..	..	5·487	..	0·100	12·137	..	0·500	7·408	..	0·400	0·758	..	E 2·500	R 0·000	..	3·000	12·896	..
Aug.	1·187	14·083	..	..	5·487	..	0·513	12·650	..	1·188	8·596	..	0·675	1·433	..	E 1·250	E 1·250	..	2·437	15·333	..
Sept.	2·667	16·750	4·354	..	5·487	..	2·350	15·000	2·963	2·666	11·262	4·354	0·317	1·750	1·392	R 1·375	R 0·125	E 2·375	1·292	16·625	6·729
Oct.	2·166	18·916	..	..	5·487	..	1·675	16·675	..	2·167	13·429	..	0·492	2·242	..	R 0·625	R 0·750	..	1·542	18·167	..
Nov.	2·458	21·374	..	0·075	5·562	..	2·050	18·725	..	2·383	15·812	..	0·408	2·650	..	R 2·000	R 2·750	..	0·458	18·625	..
Dec.	3·188	24·562	7·812	2·488	8·050	2·563	3·413	22·138	7·138	0·700	16·512	5·250	*Rev* 0·225	2·425	0·675	R 2·750	R 5·500	R 5·375	0·437	19·062	2·437
			24·562			8·050			22·138			16·512			2·425			R 5·500			19·062

TABLE XXIII.

1870.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	1·938	..	..	1·500	..	..	2·162	..	..	0·438	..	..	*Rev* 0·225	..	..	R 1·125	..	..	0·813	..	..
Feb.	0·708	2·646	..	0·500	2·000	..	1·063	3·225	..	0·208	0·646	..	*Rev* 0·354	*Rev* 0·579	..	R 0·375	R 1·500	..	0·333	1·146	..
Mar.	2·208	4·854	4·854	1·263	3·263	3·263	1·912	5·137	5·137	0·946	1·592	1·592	0·296	*Rev* 0·283	*Rev* 0·283	R 1·125	R 2·625	R 2·625	1·083	2·229	2·229
Apr.	0·417	5·271	..	0·050	3·313	..	0·663	5·800	..	0·367	1·959	..	*Rev* 0·246	*Rev* 0·529	..	E 1·875	R 0·750	..	2·292	4·521	..
May	0·687	5·958	..	..	3·313	..	0·462	6·262	..	0·687	2·646	..	0·225	*Rev* 0·304	..	E 2·500	E 1·750	..	3·187	7·708	..
June	0·500	6·458	1·604	..	3·313	0·050	0·200	6·462	1·325	0·500	3·146	1·554	0·300	*Rev* 0·004	0·279	E 3·250	E 5·000	E 7·625	3·750	11·458	9·229
July	0·688	7·146	..	..	3·313	..	0·250	6·712	..	0·687	3·833	..	0·437	0·433	..	E 2·500	R 7·500	..	3·188	14·646	..
Aug.	2·666	9·812	..	..	3·313	..	2·200	8·912	..	2·667	6·500	..	0·467	0·900	..	E 0·500	E 8·000	..	3·166	17·812	..
Sept.	2·000	11·812	5·354	..	3·313	..	2·000	10·912	4·450	2·000	8·500	5·354	..	0·900	0·904	R 0·625	R 7·375	R 2·375	1·375	19·187	7·729
Oct.	3·729	15·541	..	0·025	3·338	..	2·600	13·512	..	3·704	12·204	..	1·129	2·029	..	R 2·625	E 4·750	..	1·104	20·291	..
Nov.	1·688	17·229	..	1·112	4·450	..	2·188	15·700	..	0·575	12·779	..	*Rev* 0·500	1·529	..	R 1·250	R 3·500	..	0·488	20·729	..
Dec.	3·166	20·395	8·583	2·775	7·225	3·912	3·000	18·700	7·788	0·891	18·170	4·070	0·107	1·606	0·796	R 3·500	R 0·000	R 7·875	*Rev* 0·833	20·896	1·209
			20·395			7·225			18·700			18·170			1·000			[illegible]			20·896

1871.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·813	..	..	2·413	..	..	3·012	..	..	0·400	..	..	Rev 0·200	..	..	R 1·000	..	..	1·812	..	..
Feb.	1·437	4·250	..	1·187	3·600	..	1·463	4·475	..	0·250	0·650	..	Rev 0·025	Rev 0·225	..	R 0·875	R 1·875	..	0·563	2·375	..
Mar.	1·208	5·458	5·458	0·200	3·800	3·800	1·063	5·538	5·538	1·008	1·658	1·658	0·146	Rev 0·079	Rev 0·079	=	R 1·875	R 1·875	1·208	3·583	3·583
Apr.	2·667	8·125	..	0·150	3·950	..	2·012	7·550	..	2·517	4·175	..	0·654	0·575	..	R 1·250	R 3·125	..	1·417	5·000	..
May	0·500	8·625	..	0·175	4·125	..	0·775	8·325	..	0·325	4·500	..	Rev 0·275	0·300	..	E 2·500	R 0·625	..	3·000	8·000	..
June	2·896	11·521	6·063	0·050	4·175	0·375	2·250	10·575	5·037	2·846	7·346	5·688	0·646	0·946	1·025	R 0·625	R 1·250	E 0·625	2·271	10·271	6·688
July	3·625	15·145	..	0·025	4·200	..	2·200	12·775	..	3·600	10·946	..	1·425	2·371	..	R 0·625	R 1·875	..	3·000	13·271	..
Aug.	0·667	15·813	..	..	4·200	..	0·787	13·562	..	0·666	11·612	..	Rev 0·121	2·250	..	E 2·375	E 0·500	..	3·041	16·312	..
Sept.	4·625	20·438	8·917	0·050	4·250	0·075	2·650	16·212	5·637	4·575	16·187	8·841	1·975	4·225	3·279	R 3·000	R 2·500	R 1·250	1·625	17·937	7·666
Oct.	1·875	22·312	..	0·130	5·550	..	2·463	18·675	..	0·575	16·762	..	Rev 0·587	3·638	..	R 0·750	R 3·250	..	1·125	10·062	..
Nov.	0·416	22·728	..	..	5·550	..	0·362	19·037	..	0·417	17·179	..	0·054	3·692	..	=	R 3·250	..	0·417	19·479	..
Dec.	1·354	24·082	3·645	0·638	6·188	1·938	1·050	20·087	3·875	0·716	17·895	1·708	0·304	3·996	Rev 0·229	R 1·250	R 4·500	E 2·000	0·104	19·583	1·646
			24·083			6·188			20·087			17·895			3·996			R 4·500			19·583

TABLE XVII.

1864.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	1·083	..	..	0·637	..	..	0·850	..	..	0·446	..	..	0·233	..	..	R 0·875	..	..	0·208	..	..
Feb.	0·937	2·020	..	0·387	1·025	..	0·637	1·487	..	0·550	0·996	..	0·300	0·533	..	R 0·750	1·625	..	0·187	0·395	..
Mar.	2·708	4·728	4·728	1·837	2·862	2·862	2·437	3·924	3·924	0·870	1·866	1·866	0·271	0·804	0·804	R 1·875	R 3·500	R 3·500	0·833	1·228	1·228
Apr.	0·854	5·582	..	0·062	2·925	..	0·575	4·499	..	0·791	2·757	..	0·279	1·083	..	E 1·500	R 2·000	..	2·354	3·582	..
May	1·458	7·040	..	..	2·925	..	1·125	5·624	..	1·458	4·115	..	0·333	1·416	..	E 0·875	R 1·125	..	2·333	5·915	..
June	1·458	8·498	3·770	..	2·925	0·062	0·750	6·374	2·450	1·458	5·574	3·708	0·708	2·124	1·320	E 1·875	E 0·750	E 4·250	3·333	9·248	8·020
July	0·229	8·727	..	..	2·925	..	0·212	6·586	..	0·229	5·803	..	0·016	2·140	..	E 3·375	E 4·125	..	3·604	12·852	..
Aug.	0·937	9·664	..	..	2·925	..	0·500	7·086	..	0·937	6·740	..	0·437	2·578	..	E 1·750	E 5·875	..	2·687	15·539	..
Sept.	2·770	12·434	3·936	..	2·925	..	2·275	9·361	2·987	2·770	9·510	3·936	0·495	3·073	0·949	R 0·875	E 5·000	E 4·250	1·895	17·434	8·186
Oct.	0·833	13·267	..	..	2·925	..	0·800	10·161	..	0·833	10·343	..	0·033	3·106	..	E 0·250	E 5·250	..	1·082	18·516	..
Nov.	1·854	15·121	..	0·387	3·312	..	1·725	11·886	..	1·466	11·809	..	0·129	3·235	..	R 2·125	E 3·125	..	*Rev* 0·271	18·245	..
Dec.	0·770	15·891	3·457	0·512	3·824	0·899	0·750	12·636	3·275	0·258	12·067	2·557	0·020	3·255	0·182	R 0·375	E 2·750	R 2·250	0·395	18·640	1·206
			15·891			3·824			12·636			12·067			3·255			E 2·750			18·640

TABLE XVIII.

1865.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	3·333	..	..	2·300	..	..	2·925	..	..	1·033	..	..	0·408	..	..	R 3·375	..	..	Rev 0·042	..	..
Feb.	2·812	6·145	..	2·450	4·750	..	2·975	5·900	..	0·362	1·395	..	Rev 0·163	0·245	..	R 1·750	R 5·125	..	1·062	1·020	..
Mar.	1·000	7·145	7·145	0·675	5·425	5·425	1·100	7·000	7·000	0·325	1·720	1·720	Rev 0·100	0·145	0·145	R 0·250	R 5·375	R 5·375	0·750	1·770	1·770
Apr.	0·395	7·541	..	0·025	5·450	..	0·512	7·512	..	0·370	2·090	..	Rev 0·116	0·029	..	E 1·875	R 3·500	..	2·270	4·041	..
May	3·333	10·874	..	..	5·450	..	2·837	10·349	..	3·333	5·423	..	0·495	0·524	..	R 0·625	R 4·125	..	2·708	6·749	..
June	1·354	12·228	5·083	..	5·450	0·025	1·225	11·574	4·574	1·354	6·777	5·057	0·129	0·653	0·508	E 1·875	R 2·250	E 3·125	3·229	9·978	8·208
July	2·042	14·270	..	..	5·450	..	1·812	13·386	..	2·042	8·819	..	0·230	0·883	..	0·875	R 1·375	..	2·917	12·895	..
Aug.	5·479	19·749	..	0·825	6·275	..	4·862	18·248	..	4·654	13·473	..	0·616	1·499	..	R 1·500	R 2·875	..	3·979	16·874	..
Sept.	0·375	20·124	7·896	0·012	6·287	0·837	0·512	18·761	7·187	0·363	13·837	7·059	Rev 0·137	1·362	0·709	E 1·375	R 1·500	E 0·750	1·750	18·624	8·646
Oct.	5·812	25·936	..	2·375	8·662	..	5·312	24·073	..	3·437	17·274	..	0·500	1·862	..	R 5·250	R 6·750	..	0·562	19·187	..
Nov.	2·000	27·936	..	1·862	10·525	..	2·587	26·660	..	0·137	17·411	..	Rev 0·587	1·275	..	R 1·500	R 8·250	..	0·500	19·687	..
Dec.	1·312	29·248	9·124	0·625	11·150	4·862	1·162	27·823	9·062	0·687	18·098	4·262	0·150	1·425	0·063	R 0·875	R 9·125	R 7·625	0·437	20·124	1·500
			29·248			11·150			27·823			18·098			1·425			R 9·125			20·124

TABLE XIX.

1866.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	3·791	..	..	3·475	..	..	4·462	..	..	0·316	..	..	Rev 0·670	..	..	R 3·500	..	..	0·291	..	..
Feb.	4·229	8·020	..	3·350	6·825	..	3·887	8·349	..	0·879	1·195	..	0·341	Rev 0·329	..	R 3·375	6·875	..	0·854	1·145	..
Mar.	1·270	9·291	9·291	0·750	7·575	7·575	1·275	9·625	9·625	0·520	1·716	1·716	Rev 0·004	Rev 0·333	Rev 0·333	R 0·750	R 7·625	R 7·625	0·520	1·666	1·666
Apr.	2·395	11·686	..	0·937	8·512	..	1·962	11·586	..	1·458	3·174	..	0·433	0·100	..	R 0·125	R 7·750	..	2·270	3·936	..
May	1·354	13·040	..	..	8·512	..	1·175	12·761	..	1·354	4·528	..	0·179	0·279	..	E 1·250	R 6·500	..	2·604	6·540	..
June	4·145	17·186	7·895	0·487	9·000	1·425	3·537	16·300	6·675	3·658	8·186	6·470	0·608	0·887	1·220	R 1·750	R 8·250	R 0·625	2·395	8·936	7·270
July	1·687	18·874	..	..	9·000	..	1·312	17·612	..	1·687	9·873	..	0·375	1·262	..	E 2·250	R 6·000	..	3·937	12·873	..
Aug.	2·687	21·561	..	..	9·000	..	1·487	19·100	..	2·687	12·561	..	1·200	2·462	..	R 0·250	R 6·250	..	2·437	15·311	..
Sept.	3·480	25·041	7·855	..	9·000	..	2·700	21·800	5·500	3·480	16·041	7·855	0·780	3·242	2·355	R 1·875	R 8·125	E 0·125	1·605	16·916	7·980
Oct.	2·312	27·353	..	0·725	9·725	..	2·250	24·050	..	1·587	17·628	..	0·062	3·304	..	R 1·500	R 9·625	..	0·812	17·728	..
Nov.	1·739	29·092	..	0·975	10·700	..	1·687	25·737	..	0·764	18·392	..	0·052	3·355	..	R 1·125	R 10·750	..	0·614	18·342	..
Dec.	2·604	31·697	6·655	1·887	12·587	3·587	2·375	28·112	6·312	0·716	19·110	3·068	0·229	3·584	0·343	R 2·125	R 12·875	4·750	0·479	18·821	1·905
			31·697			12·587			28·112			19·110			3·585			R 12·875			18·821

TABLE XX.

1867.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	4·000	..	..	1·725	..	..	2·712	..	..	2·275	..	..	1·287	..	..	R 2·375	..	..	1·625	..	..
Feb.	1·937	5·937	..	1·475	3·200	..	2·075	4·787	..	0·462	2·737	..	*Rev* 0·137	1·150	..	R 0·750	R 3·125	..	1·187	2·812	..
Mar.	2·395	8·333	8·333	1·087	4·287	4·287	1·812	6·600	6·600	1·308	4·045	4·045	0·583	1·733	1·733	R 1·250	R 4·375	R 4·375	1·145	3·958	3·958
Apr.	1·979	10·312	..	0·087	4·375	..	1·437	8·038	..	1·891	5·937	..	0·541	2·274	..	R 0·375	R 4·750	..	1·604	5·562	..
May	2·520	12·833	..	..	4·375	..	1·862	9·900	..	2·520	8·458	..	0·658	2·933	..	E 0·125	R 4·625	..	2·645	8·208	..
June	1·250	14·083	5·749	..	4·375	0·087	1·112	11·012	4·412	1·250	9·708	5·662	0·137	3·070	1·337	E 2·250	R 2·375	E 2·000	3·500	11·708	7·749
July	4·541	18·624	..	..	4·375	..	3·575	14·587	..	4·541	14·249	..	0·966	4·037	..	R 1·875	R 4·250	..	2·666	14·374	..
Aug.	2·104	20·728	..	..	4·375	..	2·000	16·587	..	2·104	16·353	..	0·104	4·141	..	R=E	R 4·250	..	2·104	16·478	..
Sept.	2·083	22·812	8·729	..	4·375	..	1·550	18·137	7·125	2·083	18·437	8·729	0·533	4·674	1·604	R 0·250	R 4·500	R 2·125	1·833	18·312	6·604
Oct.	1·937	24·749	..	..	4·375	..	1·400	19·537	..	1·937	20·374	..	0·537	5·211	..	R 1·187	R 5·687	..	0·750	19·062	..
Nov.	0·145	24·895	..	..	4·375	..	0·475	20·012	..	0·145	20·520	..	*Rev* 0·329	4·882	..	E 0·062	R 5·625	..	0·208	19·270	..
Dec.	2·541	27·436	4·623	0·787	5·162	0·787	2·412	22·424	4·287	1·754	22·274	3·836	0·129	5·011	0·337	R 1·750	R 7·375	R 2·875	0·791	20·061	1·749
			27·436			5·162			22·424			22·274			5·011			R 7·375			20·061

TABLE XXI.

1868.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	3·958	..	..	3·325	..	..	4·075	..	..	0·633	..	..	*Rev* 0·117	..	..	R 3·250	..	..	0·708	..	..
Feb.	0·833	4·791	..	0·413	3·738	..	0·788	4·863	..	0·421	1·054	..	0·046	*Rev* 0·071	..	R 0·125	R 3·375	..	0·708	1·416	..
Mar.	1·646	6·437	6·437	0·075	3·813	3·813	0·937	5·800	5·800	1·571	2·625	2·625	0·708	0·637	0·637	E 0·125	R 3·250	R 3·250	1·771	3·187	3·187
Apr.	1·750	8·187	..	0·037	3·850	..	1·463	7·263	..	1·712	4·337	..	0·288	0·925	..	E 0·125	R 3·125	..	1·875	5·062	..
May	1·313	9·500	..	..	3·850	..	0·925	8·188	..	1·313	5·650	..	0·387	1·312	..	E 2·000	R 1·125	..	3·313	8·375	..
June	0·600	10·100	3·663	..	3·850	0·037	0·725	8·913	3·113	0·600	6·250	3·625	*Rev* 0·125	1·187	0·550	E 4·000	E 3·875	E 6·125	4·600	12·975	9·788
July	0·354	10·454	..	..	3·850	..	0·200	9·113	..	0·354	6·604	..	0·154	1·341	..	E 4·500	E 7·375	..	4·854	17·829	..
Aug.	2·562	13·016	..	..	3·850	..	1·712	10·825	..	2·563	9·167	..	0·850	2·191	..	E 0·375	E 7·750	..	2·937	20·766	..
Sept.	1·250	14·266	4·166	..	3·850	..	0·350	11·175	2·262	1·250	10·417	4·167	0·900	3·091	1·904	E 0·250	E 8·000	E 5·125	1·500	22·266	9·291
Oct.	2·667	16·933	..	..	3·850	..	2·950	14·125	..	2·666	13·083	..	*Rev* 0·283	2·808	..	R 1·500	E 6·500	..	1·167	23·433	..
Nov.	1·000	17·933	..	..	3·850	..	1·138	15·263	..	1·000	14·083	..	*Rev* 0·138	2·670	..	E 1·625	E 8·125	..	2·625	26·058	..
Dec.	5·375	23·308	9·042	3·262	7·112	3·262	4·937	20·000	9·025	2·113	16·196	5·779	0·438	3·108	0·017	R 4·500	E 3·625	R 4·375	0·875	26·933	4·667
			23·308			7·112			20·200			16·196			3·108			E 3·625			26·933

TABLE XXII.

1869.	Rain.			Percolation.						Evaporation.											
				Ground.			Sand.			Ground.			Sand.			Box.			Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·959	..	..	2·500	..	..	3·162	..	..	0·458	..	..	Rev 0·204	..	..	R 2·250	..	..	0·708	..	..
Feb.	2·583	5·542	..	2·100	4·600	..	2·788	5·950	..	0·483	0·941	..	Rev 0·204	Rev 0·408	..	R 1·500	R 3·750	..	1·083	1·791	..
Mar.	1·458	7·000	7·000	0·725	5·325	5·325	1·412	7·362	7·362	0·733	1·674	1·674	0·046	Rev 0·362	Rev 0·362	R 0·500	R 4·250	R 4·250	0·959	2·750	2·750
Apr.	1·167	8·167	..	0·050	5·375	..	1·063	8·425	..	1·117	2·791	..	0·104	Rev 0·258	..	E 0·625	R 3·625	..	1·792	4·542	..
May	3·250	11·417	..	0·112	5·487	..	2·750	11·175	..	3·138	5·929	..	0·500	0·242	..	R 0·875	R 4·500	..	2·375	6·917	..
June	0·979	12·396	5·396	..	5·487	0·162	0·862	12·037	4·675	0·979	6·908	5·234	0·116	0·358	0·720	E 2·000	R 2·500	E 1·750	2·979	9·896	7·146
July	0·500	12·896	..	..	5·487	..	0·100	12·137	..	0·500	7·408	..	0·400	0·758	..	E 2·500	R 0·000	..	3·000	12·896	..
Aug.	1·187	14·083	..	..	5·487	..	0·513	12·650	..	1·188	8·596	..	0·675	1·433	..	E 1·250	E 1·250	..	2·437	15·333	..
Sept.	2·667	16·750	4·354	..	5·487	..	2·350	15·000	2·963	2·666	11·262	4·354	0·317	1·750	1·392	R 1·375	R 0·125	E 2·375	1·292	16·625	6·729
Oct.	2·166	18·916	..	..	5·487	..	1·675	16·675	..	2·167	13·429	..	0·492	2·242	..	R 0·625	R 0·750	..	1·542	18·167	..
Nov.	2·458	21·374	..	0·075	5·562	..	2·050	18·725	..	2·383	15·812	..	0·408	2·650	..	R 2·000	R 2·750	..	0·458	18·625	..
Dec.	3·188	24·562	7·812	2·488	8·050	2·563	3·413	22·138	7·138	0·700	16·512	5·250	Rev 0·225	2·425	0·675	R 2·750	R 5·500	R 5·375	0·437	19·062	2·437
			24·562			8·050			22·138			16·512			2·425			R 5·500			19·062

TABLE XXIII.

1870.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	1·938	..	..	1·500	..	..	2·162	..	..	0·438	..	..	*Rev* 0·225	..	..	R 1·125	..	..	0·813	..	..
Feb.	0·708	2·646	..	0·500	2·000	..	1·063	3·225	..	0·208	0·646	..	*Rev* 0·354	*Rev* 0·579	..	R 0·375	R 1·500	..	0·333	1·146	..
Mar.	2·208	4·854	4·854	1·263	3·263	3·263	1·912	5·137	5·137	0·946	1·592	1·592	0·296	*Rev* 0·283	*Rev* 0·283	R 1·125	R 2·625	R 2·625	1·083	2·229	2·229
Apr.	0·417	5·271	..	0·050	3·313	..	0·663	5·800	..	0·367	1·959	..	*Rev* 0·246	*Rev* 0·529	..	E 1·875	R 0·750	..	2·292	4·521	..
May	0·687	5·958	..	..	3·313	..	0·462	6·262	..	0·687	2·646	..	0·225	*Rev* 0·304	..	E 2·500	E 1·750	..	3·187	7·708	..
June	0·500	6·458	1·604	..	3·313	0·050	0·200	6·462	1·325	0·500	3·146	1·554	0·300	*Rev* 0·004	0·279	E 3·250	E 5·000	E 7·625	3·750	11·458	9·229
July	0·688	7·146	..	..	3·313	..	0·250	6·712	..	0·687	3·833	..	0·437	0·433	..	E 2·500	E 7·500	..	3·188	14·646	..
Aug.	2·666	9·812	..	..	3·313	..	2·200	8·912	..	2·667	6·500	..	0·467	0·900	..	E 0·500	E 8·000	..	3·166	17·812	..
Sept.	2·000	11·812	5·354	..	3·313	..	2·000	10·912	4·450	2·000	8·500	5·354	..	0·900	0·904	R 0·625	E 7·375	E 2·375	1·375	19·187	7·729
Oct.	3·729	15·541	..	0·025	3·338	..	2·600	13·512	..	3·704	12·204	..	1·129	2·029	..	R 2·625	E 4·750	..	1·104	20·291	..
Nov.	1·688	17·229	..	1·112	4·450	..	2·188	15·700	..	0·575	12·779	..	*Rev* 0·500	1·529	..	R 1·250	E 3·500	..	0·438	20·729	..
Dec.	3·166	20·395	8·583	2·775	7·225	3·912	3·000	18·700	7·788	0·391	13·170	4·670	0·167	1·696	0·796	R 3·500	E 0·000	R 7·375	*Rev* 0·333	20·396	1·209
			20·395			7·225			18·700			13·170			1·696			R = E			20·396

TABLE XXIV.

1871.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·813	..	..	2·413	..	..	3·012	..	..	0·400	..	..	*Rev* 0·200	..	..	R 1·000	..	..	1·812	..	..
Feb.	1·437	4·250	..	1·187	3·600	..	1·463	4·475	..	0·250	0·650	..	*Rev* 0·025	*Rev* 0·225	..	R 0·875	R 1·875	..	0·563	2·375	..
Mar.	1·208	5·458	5·458	0·200	3·800	3·800	1·063	5·538	5·538	1·008	1·658	1·658	0·146	*Rev* 0·079	*Rev* 0·079	=	R 1·875	R 1·875	1·208	3·583	3·583
Apr.	2·667	8·125	..	0·150	3·950	..	2·012	7·550	..	2·517	4·175	..	0·654	0·575	..	R 1·250	R 3·125	..	1·417	5·000	..
May	0·500	8·625	..	0·175	4·125	..	0·775	8·325	..	0·325	4·500	..	*Rev* 0·275	0·300	..	E 2·500	R 0·625	..	3·000	8·000	..
June	2·896	11·521	6·063	0·050	4·175	0·375	2·250	10·575	5·037	2·846	7·346	5·688	0·646	0·946	1·025	R 0·625	R 1·250	E 0·625	2·271	10·271	6·688
July	3·625	15·145	..	0·025	4·200	..	2·200	12·775	..	3·600	10·946	..	1·425	2·371	..	R 0·625	R 1·875	..	3·000	13·271	..
Aug.	0·667	15·813	..	..	4·200	..	0·787	13·562	..	0·666	11·612	..	*Rev* 0·121	2·250	..	E 2·375	E 0·500	..	3·041	16·312	..
Sept.	4·625	20·438	8·917	0·050	4·250	0·075	2·650	16·212	5·637	4·575	16·187	8·841	1·975	4·225	3·279	R 3·000	R 2·500	R 1·250	1·625	17·937	7·666
Oct.	1·875	22·312	..	0·130	5·550	..	2·463	18·675	..	0·575	16·762	..	*Rev* 0·587	3·638	..	R 0·750	R 3·250	..	1·125	10·062	..
Nov.	0·416	22·728	..	..	5·550	..	0·362	19·037	..	0·417	17·179	..	0·054	3·692	..	=	R 3·250	..	0·417	19·479	..
Dec.	1·354	24·082	3·645	0·638	6·188	1·938	1·050	20·087	3·875	0·716	17·895	1·708	0·304	3·996	*Rev* 0·229	R 1·250	R 4·500	E 2·000	0·104	19·583	1·646
			24·083			6·188			20·087			17·895			3·996			R 4·500			19·583

TABLE XXV.

1872.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	In	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	4·229	..	..	3·500	..	..	4·562	..	..	0·729	..	..	*Rev* 0·333	..	..	R 3·250	..	..	0·979	..	..
Feb.	0·979	5·208	..	0·337	3·837	..	0·475	5·037	..	0·642	1·371	..	0·504	0·171	..	R 0·500	R 3·750	..	0·479	1·458	..
Mar.	3·000	8·208	8·208	1·025	4·862	4·862	2·275	7·312	7·312	1·975	3·346	3·346	0·725	0·896	0·896	R 1·375	R 5·125	R 5·125	1·625	3·083	3·083
Apr.	2·125	10·333	..	0·738	5·600	..	1·513	8·825	..	1·387	4·733	..	0·613	1·508	..	E 0·125	R 5·000	..	2·250	5·333	..
May	3·333	13·666	..	0·325	5·925	..	2·662	11·487	..	3·008	7·741	..	0·670	2·179	..	R 0 500	R 5·500	..	2·833	8·166	..
June	2·167	15·833	7·625	..	5·925	1·063	1·488	12·975	5·663	2·167	9·908	6·562	0·679	2·858	1·962	E 1·000	R 4·500	E 0·625	3·167	11·333	8·250
July	2·021	17·854	..	..	5·925	..	0·925	13·900	..	2·021	11·929	..	1·096	3·954	..	E 1·000	R 3·500	..	3·021	14·354	..
Aug.	3·583	21·437	..	..	5·925	..	2·787	16·687	..	3·583	15·512	..	0·796	4·750	..	R 0·625	R 4·125	..	2·958	17·312	..
Sept.	1·417	22·854	7·021	..	5·925	..	0·800	17·487	4·512	1·417	16·929	7·021	0·617	5·367	2·508	E 0·500	R 3·625	E 0·875	1·917	19·229	7·896
Oct.	5·333	28·187	..	0·675	6·600	..	4·150	21·637	..	4·658	21·587	..	1·183	6·550	..	R 3·875	R 7·500	..	1·458	20·687	..
Nov.	3·646	31·833	..	1·738	8·338	..	3·400	25·037	..	1·908	23·495	..	0·246	6·896	..	R 3·125	R 10·625	..	0·521	21·208	..
Dec.	5·333	37·166	14·312	3·687	12·025	6·100	5·013	30·050	12·563	1·646	25·141	8·212	0·321	7·217	1·750	R 3·625	R 14·250	R 10·625	1·708	22·916	3·687
			37·166			12·025			30·050			25·141			7·116			R 14·250			22·916

TABLE XXVI.

1873.	Rain.			Percolation. Ground.			Percolation. Sand.			Evaporation. Ground.			Evaporation. Sand.			Evaporation. Box.			Evaporation. Water.		
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Jan.	2·458	..	..	1·612	..	..	2·675	..	..	0·846	..	..	Rev 0·217	..	..	R 1·500	..	..	0·958	..	..
Feb.	2·021	4·479	..	0·863	2·475	..	1·775	4·450	..	1·158	2·004	..	0·246	0·029	..	R 1·750	R 3·250	..	0·271	1·229	..
Mar.	1·542	6·021	6·021	0·463	2·938	2·938	1·387	5·837	5·837	1·079	3·083	3·083	0·154	0·183	0·183	R 0·250	R 3·500	R 3·500	1·291	2·520	2·520
Apr.	0·687	6·708	..	..	2·938	..	0·738	6·575	..	0·687	3·770	..	Rev 0·050	0·133	..	E 1·375	R 2·125	..	2·063	4·583	..
May	2·063	8·771	..	..	2·938	..	1·475	8·050	..	2·063	5·833	..	0·588	0·721	..	E 1·000	R 1·125	..	3·062	7·646	..
June	2·312	11·083	5·062	..	2·938	..	1·375	9·425	3·588	2·312	8·145	5·062	0·937	1·658	1·475	E 0·125	R 1·000	E 2·500	2·437	10·083	7·562
July	2·063	13·146	..	..	2·938	..	1·900	11·325	..	2·063	10·208	..	0·163	1·821	..	E 1·625	E 0·625	..	3·687	13·770	..
Aug.	2·250	15·396	..	..	2·938	..	1·187	12·512	..	2·250	12·458	..	1·062	2·883	..	E 0·500	E 1·125	..	2·750	16·520	..
Sept.	2·562	17·958	6·875	..	2·938	..	2·375	14·887	5·462	2·562	15·020	6·875	0·188	3·071	1·413	R 0·875	E 0·250	E 1·250	1·688	18·208	8·125
Oct.	2·750	20·708	..	..	2·938	..	2·313	17·200	..	2·750	17·770	..	0·437	3·508	..	R 2·250	R 2·000	..	0·500	18·708	..
Nov.	2·771	23·479	..	1·087	4·025	..	3·312	19·512	..	1·684	19·454	..	0·458	3·966	..	R 1·250	R 3·250	..	1·521	20·229	..
Dec.	0·291	23·770	5·812	0·025	4·050	1·112	0·608	20·120	5·233	0·267	19·721	4·701	Rev 0·316	3·650	0·580	R 0·125	R 3·375	R 3·625	0·167	20·396	2·188
			23·770			4·050			20·120			19·721			3·650			R 3·375			20·395

Mr. Greaves remarked that the river Lee was in the peculiar position of yielding the supply of water for one-half the population of London. It would therefore be easily understood, that the investigation into the flow of that river, and the quantity of water obtainable from it, was of great interest to water companies and to those in charge of waterworks. It so happened that the intake of the New River Company was just above that of the East London waterworks. As the Engineer of the Company last named, he had made the fluctuations of the river a continual study, to ascertain whether they were due to natural causes, or to any special operations. The investigation brought out a number of interesting results. The inquiry was undertaken on practical grounds, and arose out of an absolute necessity to know something of the subject, not from a desire to support any particular view. One of the results mentioned in the Paper had not been previously understood, at least thoroughly, that the state of rivers could be predicted nine months before the autumn season. He had not ascertained whether the percolation was sufficient to indicate the proportion of rainfall which rivers yielded in their flow off the ground, but that inquiry would, he had no doubt, be soon followed out. The form of gauge referred to in the Paper, of which a model was exhibited, he had first heard of from Mr. Golding at Copenhagen, who was in charge of the State waterworks there. It would be observed that the edge of the inner tank was level with that of the outer one. The records of evaporation in Beardmore's "Manual of Hydrology" were from a tank similar to the inner one. Mr. Dickinson's observations would, he believed, be referred to; also others, carried out subsequently for the Rivers Pollution Commission, in a large lead tank having an area of a thousandth part of an acre, the water being led from the tank into a reservoir: that was a percolation gauge, but neither had any floating water gauge. Instead of bringing forward the results of the observations of two thousand persons, he had only the results of one observer, which therefore needed corroboration; he did not, however, believe that engineers would underrate the facts derivable from his method of investigation.

Mr. John Evans wished to express the gratification he was sure must be felt at the lucid manner in which the subject had been brought forward. With regard to the first Paper he had not much to say, but it entered into a supplementary matter on which he should like to offer some remarks. Before, however, referring to the latter part of the Paper, he would venture to say a few words on behalf of those "unprofitable mills, which should not be allowed

to cause the flooding of thousands of acres." He thought that, in an assembly of engineers, the most valuable of all powers, because the least costly, namely, water power, ought not to be underrated. He could not understand how mills of necessity caused the slightest mischief. The method adopted in his neighbourhood, and which ought to be adopted in all districts where there were permeable soils, was simply to have a ditch on each side of the elevated portion of the stream which formed the mill-head, at a lower level than the natural drainage of the valley. If there was such a side-stream to keep the waters of the valley at their natural level, or something below it, it would be utterly impossible for the mills, whether profitable or otherwise, to injure the neighbouring land. That was a point of such simplicity that it was needless to insist further upon it. With regard to another matter, raised also in the Sixth Report of the Rivers Pollution Commission, as to the supply of London being derived from rivers or deep wells, there could, he thought, be little doubt that in many cases, under favourable conditions, the water in deep wells was of a higher degree of purity than that of the neighbouring streams, but it was not invariably the case. By referring to the analyses given in the report of the Commissioners, it would be found, under the awful heading, "Previous Sewage Contamination," that the water from the wells of the Kent Company contained a much larger percentage than the water of the river companies supplying London.[1] But it was said that it did not matter if there was an amount of even 10 per cent. of previous sewage contamination in deep well water; that it was only when it was found in the streams that it became so intensely dangerous. Now, if deep well water were regarded, as it ought to be, as water on its way to delivery by springs, and if the water delivered by those springs contained the same amount of previous sewage contamination as it did when it was in the deep well, the water flowing in the river would, as it came from its source, contain that same amount of contamination, and would be condemned as utterly unfit to be drunk by the human race. He was thankful to find that there were so many survivors in London who had subsisted upon water of that quality, notwithstanding the dangers to which they were subjected, and these were by no means to be underrated. But it remained for engineers to say, whether everything had been done with regard to

[1] *Vide* Rivers Pollution Commission (1868). Sixth Report, p. 275.

river waters which could be done towards purifying them, and towards depriving them of that organic matter and those germs which were considered so injurious to health. The hardness of waters had been alluded to, and he thought there could be little doubt that, in the majority of cases for domestic purposes, the presence of so large an amount of carbonate of lime, as was found in deep well water in the chalk, or in the rivers flowing out of the chalk, was objectionable; but that might be removed by the decalcifying process of Dr. Clark, and it was a question whether in that process of depositing the carbonate of lime a considerable amount of organic matter might not at the same time be precipitated. That being done, it became another question whether the water might not be still further purified by some process of artificial aeration, without involving any enormous expense; and then the benefit of filtration might be immensely increased by merely adding a few inches to the depth of the filter-bed. He maintained that it was a question for engineers to decide, whether the river water supplied to London might not be purified, as was the opinion of the Commissioners, so as to make it sufficiently wholesome. With reference to the question of chemical purity, it was a matter for consideration, whether it was worth while to be at the expense of importing into London 120,000,000 gallons of pure water every day in order that 110,000,000 gallons of it might be sent down the sewers, or be used for watering the roads. It appeared to be the height of folly to entertain schemes involving such an expenditure for the purpose of bringing water into London of great chemical purity, which, after all, was to be wasted in such a manner. If it was desirable to drink nothing but deep well water, enough was already supplied for that purpose. The Kent Water Company alone supplied 2¼ gallons daily for every inhabitant of the metropolitan area. Another question, which might fairly be considered, was whether there were not means of obtaining a double service, the one of pure drinking-water for domestic use, and the other of water of more ordinary quality for flushing sewers and watering roads. There was another way in which that question would react, but that was a subject on which, perhaps, as an interested party, he ought not to say much. He might, however, be permitted to point out that, in order to supply the wants of the metropolitan area, taking the population at four millions, and allowing each person 30 gallons a day, it would be necessary in years in which the percolation through the soil was only 4 inches (a not unfrequent occurrence) to drain an area of between 600 and 700

square miles, and to drain it in such a manner that every stream flowing through it, and all the wells on which the inhabitants depended would become dry. It might be very agreeable to some of the inhabitants of the metropolis to think that they were to be supplied with perfectly pure water, but it was a matter of no less importance to those whose water was to be conveyed away.

With reference to the second Paper, he was to some extent thankful to the Author, and to some extent the reverse, inasmuch as a communication he had intended to present to the Institution had been anticipated. The gauges which originally induced Mr. Greaves to make his observations, and which were first established by Mr. Dickinson, had been superintended by himself partly during that gentleman's lifetime, and subsequently down to the present time. The results were generally in accordance with those of Mr. Greaves, though they did not show quite so much percolation: that no doubt was to a considerable extent dependent upon the nature of the soil with which the gauges were filled, and it was difficult to represent an average soil. One of their gauges was filled with the ordinary surface soil of the country, consisting of gravel, loam, and mould, and the other was filled with pure chalk; and it was found that the percolation through the latter (on the surface of which turf was grown in the same manner as in the other) was considerably greater than that through the former. He presumed that with Mr. Greaves's sand gauge nothing was allowed to grow upon the surface. He did not agree in the opinion that when once water had arrived at a depth of from 1 foot to 2 feet below the surface it was beyond the reach of atmospheric influences. He could not help thinking that the power of capillary attraction had been underrated. Professor Ansted had made an experiment with blocks of chalk, 1 cubic inch in size, placed in a tube. The bottom of the tube was put in a pail of water, and it was found that the chalk was wetted at a height, he believed, of 16 feet from the water. There was another point as to which he would suggest an improvement in the tables. It was found that what might be called the meteoric year, the year of percolation, consisted of a summer half, during which hardly any percolation occurred, and a winter half, during which nearly the whole of the percolation took place; and that if the year was made to end on the 31st of December a false idea was obtained as to the amount of percolation. It was better to adopt the principle followed by Mr. Dickinson, and by himself in the tables he

communicated to the Institution fifteen years ago,[1] of making the rainfall and the percolation year terminate on the 31st of March: it gave a better insight into what was really going on, and rendered it more easy to predict the results during the ensuing season.

Dr. Gilbert remarked that Mr. Lawes and himself had been for some time engaged in percolation experiments as well as in rain-gauge determinations. He had accordingly arranged a few facts connected with those experiments extending over a period of five years. He could not give the results of so many years as Mr. Greaves, nor were theirs obtained under exactly parallel conditions. They were undertaken with a different view, their object being an agricultural one, in relation to vegetation, and the characters of soils. Mr. Greaves's percolation gauge was filled with soil artificially; they, on the other hand, took the soil just as it was; they dug down and undermined it, putting iron plates which were drilled with holes underneath; they gradually got it underpinned in that way, and built it in with brick and cement, so that they had an isolated square of soil entirely undisturbed. The area of each gauge was one-thousandth of an acre. They had one such gauge with 20 inches, one with 40 inches, and one with 60 inches depth of soil; so that they were able to answer some of the questions with regard to capillary action to which reference had been made. Of previous determinations Dr. Dalton's had indicated that 25 per cent. of the rain percolated; those of Mr. Dickinson showed up to a certain date 42·5 per cent.; those of M. Maurice, at Geneva, 39 per cent.; those of M. Gasparin, in the South of France, 20 per cent.; those of M. Risler, near Geneva, 30 per cent.: or an average of 31·3 per cent. under different conditions in five different localities. Mr. Greaves gave 28 per cent. For a period of five years Mr. Lawes and himself found 36·8 per cent. of the rainfall percolating through 20 inches, 36 per cent. through 40 inches, and 28·6 per cent. through 60 inches. They had a natural soil, a subsoil with its natural consolidation; whereas Mr. Greaves's was an artificial soil, a much more open soil than the materials of which it was composed would form in their natural condition. (See Table I., *post*, p. 56.) The particulars of experiments on percolation by Ebermayer, in Bavaria, were given in Tables II. and III., *post*, pp. 57 and 58. To show how difficult it was to imitate soil in its natural condition, he might mention that, wishing to extend their experiments, they attempted

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 220.

to fill, by calculation, a number of tubes, 5 feet deep and 2 feet in diameter, with the soil of the immediately adjoining field in its exact natural condition. After putting in 3 feet of soil, pouring a great deal of water through, and applying a weight of more than 1 ton for many months, the soil had not sunk down to the 3 feet by about 6 inches. It was almost impossible by artificial means to get a soil like the natural one. Another difference in the mode of estimation was that they took the harvest year, from the 1st of September to the end of August. The rainfall in the first year was 27½ inches; in the succeeding years 29 inches, 30½ inches, 21¾ inches, and 30¾ inches, or an average of nearly 28 inches. Of those 28 inches about 10¼ inches percolated through 20 inches, 10 inches through 40 inches, and only 8 inches through 60 inches of soil; so that it was clear that capillary action had had its effect far below the depth Mr. Greaves supposed. In fact it was obvious that it had been operative below 40 inches, as was illustrated in the more detailed figures. Beginning in September, that was after warm and comparatively dry weather, there was less water going through 40 inches than through 20 inches, and less through 60 inches than through 40 inches depth of soil; and so it went on until the winter rains accumulated, when the reverse happened, and there was sometimes more through the 60 inches than through the 20 inches. (See Tables IV. and V., *post*, pp. 59 and 60.) Capillary action therefore certainly had its influence on percolation, or rather on evaporation—the complement to it—far below the depth that had been mentioned. Mr. Greaves's observations indicated an average of about 7 inches of percolation. This determination rested upon experiments made on soil covered with vegetation, and of course the surface of the country was mostly so covered; but the amount of vegetation much determined the amount of percolation.

Ebermayer quoted Professor Woldrich as having determined the amount of percolation (2 feet deep) through turf, and through bare ground, at Salzburg and in the neighbourhood of Vienna. At Salzburg the percolation was—

In May	25·2	per cent. less	through turf.
„ June	53·1	„	„
„ July	23·4	„	„
„ Aug.	29·2	„	„
„ Sept.	12·7	„	„

The difference was the least in January. In May, both at Salzburg and at Vienna, more than twice as much percolated

through bare earth as through turf. From June 16–30 there percolated at Salzburg—

2·12 inches (Eng.) through bare earth.
0·02 „ „ „ turf.

The maximum difference was in June and July, and less in autumn and winter. Ebermayer concluded that in the summer half-year forest soil was the moistest; bare, open ground less moist; turf the driest.

From the results of an extended series of experiments on the amount of water given off by plants during their growth, it might be roughly estimated that, for every ton of really dry substance grown, a depth of 3 inches of rain would be evaporated through the vegetation. For every ton of hay, in its natural condition, about 2½ inches of rain would pass through the plant. It was obvious that, where there was vegetation, percolation would be diminished, and especially where the growth extended through nearly the whole of the year, as in the case of grass land. The water would not be safe until it reached a lower depth than if the land were not covered, as in the case of the percolation experiments to which he had referred. (See Tables VI. and VII., *post*, p. 61.) He thought that the larger amounts of percolation obtained in their own experiments than in those of Mr. Greaves were the resultant of two opposite agencies: they had no vegetation to pump the water out, but, on the other hand, Mr. Greaves's soil had no doubt been more pervious than theirs.

M. Marié-Davy, Director of the Meteorological Observatory, at Montsouris, Paris, had also made numerous experiments on the amount of water evaporated by different plants during growth, and also on the amount evaporated from soils of different kinds, or covered with different descriptions of vegetation; but the results were too numerous and varied to be conveniently summarised in a tabular form.

With reference to some observations by Mr. Symons, he might be permitted to refer to the effects of manures in fouling water. When that gentleman visited them some time ago, he pointed out two plots of wheat, one of which had been manured in the autumn, and the other in the spring. There had been a wet winter, and under those conditions the crop manured in the spring was much better than that manured in the autumn. In dry winters it was just the contrary. At such times the crop manured in the autumn picked up more of the active manures, which did not get into the drains, so that there was a better root-distribution, and eventually a

better crop. Those experiments on the growth of wheat had been carried on for more than thirty years. The drain of each plot was opened, and the drainage-water occasionally collected for analysis. Dr. Voelcker and Dr. Frankland had analysed many of those waters. The results showed, on an average, that where no nitrogenous manure had been used for many years, the amount of nitrogen in the drainage-water was 0·43 part per 100,000; when 41 lbs. of nitrogen per acre per annum were put on in the form of ammonia salts, the amount was 0·82 part; with 82 lbs., 1·44 part; with 123 lbs., 1·81 part; almost progressing in the ratio of the amount of nitrogen put upon the soil. Two analyses by Dr. Voelcker and four by Dr. Frankland gave 1·26 part of nitrogen per 100,000 parts of drainage-water from land manured every year with farmyard manure. (See Table VIII., *post*, p. 62.) Some of the plots were manured far more heavily than was usual in agriculture, so that there need be no fear of anything like the fouling of water referred to from ordinary agricultural operations. Of course it would be more in light soils than in heavy lands. The results described had been obtained in somewhat heavy soil. The importance of watching the matter was very great. He did not, however, think that when the matters had passed through a considerable depth of soil there was so much danger from ordinary agriculture as was sometimes supposed, although it was true the drainage-water might not indicate a very good previous history.

The following tables embodied summaries of the results to which he had referred (see pp. 56–62).

TABLE I.—PERCOLATION and EVAPORATION; SUMMARY of the RESULTS of VARIOUS OBSERVERS.

Authority.	Conditions of the Experiments, &c.	Duration and Dates.		Percolation.	Evaporation.
		Years.		Per cent.	Per cent.
Dr. Dalton	("Mem. Lit. Phil. Soc. of Manchester," vol. v., part 2.) Cylinder 10 inches diameter, 3 feet deep, open at top, closed at bottom; filled with earth and sunk into the ground level with the surface; one side left exposed for access to bottles—after first year surface of soil covered with grass	3	1796–1798	25·0	75·0
Mr. Dickinson	("Jour. Royal Agric. Soc.," vol. v.). Cylinder 12 inches diameter, 3 feet deep; perforated bottom with receptacle for collection of drainage water; grass was grown on the surface of the soil (a sandy gravelly loam) in the cylinder; evaporation included that due to vegetable growth. Average rainfall during 8 years = 26·61 inches	8	1836–1843	42·5	57·5
M. Maurice	Geneva ("Bibl. Universelle de Genève, Sciences et Arts," t. 1). Cylindrical iron vessel with earth, rainfall averaged over two years about 26 inches per annum	2	1796 and 1797	39·0	61·0
M. Gasparin	Orange, South of France ("Cours d'Agriculture," t. ii., p. 116). Experiments somewhat similar to those of M. Maurice. Average rainfall 28 inches per annum	2	1821 and 1822	20·0	80·0
M. Risler	Calèves, near Nyon, Switzerland ("Archives des Sciences de la Bibliothèque Universelle," Sept. 1869). By gauging drains 1·2 mètre (about 4 feet) deep; compact and impervious subsoil; land cropped, as usual, during experiment; average rain 41 inches per annum; evaporation includes that due to vegetable growth	2	1867 and 1868	30·0	70·0
			Mean	31·3	68·7
Mr. Greaves	Lee Bridge. Gauge, slate box; area 1 square yard, 1 yard deep; soil, soft earth with loam, gravel and sand mixed, trodden in, and turfed; average rainfall 25·8 inches	22	1852–1873	26·6	73·4
	Similar gauge; with sand; average rainfall 25·7 inches	14	1860–1873	83·2	16·8
	Estimated average for Home Counties; rainfall 25 inches	..	..	28·0	72·0
Lawes and Gilbert	Rothamsted, Herts. Gauge one-thousandth of an acre area; soil, rather heavy loam with clay subsoil, built in, in natural state of consolidation, with brick and cement. Average rainfall 28 inches. 20 ins. deep	5	Sept. 1870—Aug. 1875	36·8	63·2
	Do. do. do. 40 " "	5	Sept. 1870—Aug. 1875	36·0	64·0
	Do. do. do. 60 " "	5	Sept. 1870—Aug. 1875	28·6	71·4

TABLE II.—EXPERIMENTS on PERCOLATION, by EBERMAYER, in BAVARIA.

Gauge.—A zinc cylinder, with an area of 1 square foot, and 1, 2, or 4 feet (Fr.) deep, filled with adjacent soil and exposed to air and rain for some time to acquire normal physical characters.

—	Percolation through Soil. Inches (English).			
	1 foot deep.[1]	2 feet deep.[1]	4 feet deep.[1]	Average Rainfall.
12 Months, March 1868—*Feb.* 1869; *Mean of* 4 *Stations.*				
Open ground, bare	20·01	18·08	19·41	36·0
Forest, without litter	18·56	..	..	27·5
„ with litter	20·63	21·48	16·54	
Spring. March, April, May 1868.				
Open ground, bare	5·22	5·35	5·86	
Forest, without litter	4·99	..	..	
„ with litter	5·69	5·75	6·00	
„ with litter + or − open ground	+0·47	+0·40	+0·14	
Summer. June, July, August 1868.				
Open ground, bare	2·26	1·62	1·09	
Forest, without litter	4·12	..	..	
„ with litter	5·77	5·42	3·00	
„ with litter + or − open ground	+3·51	+3·80	+1·91	
Autumn. Sept., Oct., Nov. 1868.				
Open ground, bare	4·41	4·08	4·09	
Forest, without litter	3·96	..	..	
„ with litter	3·84	4·52	3·48	
„ with litter + or − open ground	−0·57	+0·44	−0·61	
Winter. Dec., Jan., Feb. 1868–9.				
Open ground, bare	8·13	7·06	8·36	
Forest, without litter	5·49	..	..	
„ with litter	5·34	5·78	4·07	
„ with litter + or − open ground	−2·79	−1·28	−4·29	
Growing Period. April—September, inclusive, 1868.				
Open ground, bare	5·40	4·90	4·69	
Forest, without litter	7·62	..	..	
„ with litter	9·69	9·84	7·13	
„ with litter + or − open ground	+4·29	+4·29	+2·44	

[1] French feet.

TABLE III.—EXPERIMENTS on PERCOLATION, by EBERMAYER, in BAVARIA.

Gauge.—A zinc cylinder, with an area of 1 square foot, and 1, 2, or 4 feet (Fr.) deep, filled with adjacent soil and exposed to air and rain for some time to acquire normal physical characters.

Percentage of Percolation to Rainfall.

—	Percolation through Soil. Per cent. of Rainfall.		
	1 foot deep.[1]	2 feet deep.[1]	4 feet deep.[1]
12 Months, March 1868—Feb. 1869; Mean of 4 Stations.			
Open ground, bare	54	50	53
Forest, without litter	67	..	..
„ with litter	74	77	60
Spring. March, April, May 1868.			
Open ground, bare	55	56	64
Forest, without litter	70	..	..
„ with litter	81	81	83
Summer. June, July, August 1868.			
Open ground, bare	19	14	11
Forest, without litter	52	..	..
„ with litter	72	65	36
Autumn. Sept., Oct., Nov. 1868.			
Open ground, bare	54	51	49
Forest, without litter	60	..	..
„ with litter	60	68	54
Winter. Dec., Jan., Feb. 1868–9.			
Open ground, bare	94	89	99
Forest, without litter	91	..	..
„ with litter	94	97	63
Comparison of Winter and Summer Half-years.			
Open ground, bare — Oct.—March	72	67	76
Open ground, bare — April—Nov.	23	24	24
Summer less than winter	49	43	52
Forest, without litter — Oct.—March	80	..	..
Forest, without litter — April—Nov.	57	..	..
Summer less than winter	23	..	..
Forest, with litter — Oct.—March	86	87	73
Forest, with litter — April—Nov.	75	76	62
Summer less than winter	11	11	11
July only.			
Open ground, bare	11	6	7
Forest, with litter	58	61	34

[1] French feet.

TABLE IV.—RAIN and PERCOLATION at ROTHAMSTED, HERTS.
September 1, 1870, *to August* 31, 1875.

—	Rainfall.	Percolation through Soil.			Difference reckoned as Evaporation.		
		20 inches deep.	40 inches deep.	60 inches deep.	20 inches deep.	40 inches deep.	60 inches deep.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Sept. 1870—Aug. 1871	27·55	9·64	9·42	5·81	17·91	18·13	21·74
„ 1871 „ 1872	29·02	9·69	9·40	8·24	19·33	19·62	20·78
„ 1872 „ 1873	30·66	14·35	13·67	12·03	16·31	16·99	18·63
„ 1873 „ 1874	21·69	5·47	5·11	3·61	16·22	16·58	18·08
„ 1874 „ 1875	30·74	12·25	12·72	10·30	18·49	18·02	20·44
Average per annum .	27·93	10·28	10·06	8·00	17·65	17·87	19·93
September	2·88	0·68	0·43	0·30	2·20	2·45	2·58
October	3·19	1·37	1·09	0·76	1·82	2·10	2·43
November	2·08	1·41	1·30	1·01	0·67	0·78	1·07
December	2·15	1·52	1·51	1·14	0·63	0·64	1·01
January	3·11	2·15	2·43	2·08	0·96	0·68	1·03
February	1·47	0·69	0·75	0·59	0·78	0·72	0·88
March	1·43	0·53	0·57	0·47	0·90	0·86	0·96
April	1·76	0·26	0·28	0·22	1·50	1·48	1·54
May	1·91	0·21	0·23	0·19	1·70	1·68	1·72
June	2·77	0·48	0·43	0·36	2·29	2·34	2·41
July	3·47	0·97	1·03	0·87	2·50	2·44	2·60
August	1·71	0·01	0·01	0·01	1·70	1·70	1·70
Total	27·93	10·28	10·06	8·00	17·65	17·87	19·93
Average per month .	2·33	0·86	0·84	0·67	1·47	1·49	1·66

TABLE V.—RAIN and PERCOLATION at ROTHAMSTED, HERTS.
September 1, 1870, *to August* 31, 1875.

—	Rainfall.	Percentage of Percolation to Rainfall.					
		Percolation through Soil.			Difference reckoned as Evaporation.		
		20 inches deep.	40 inches deep.	60 inches deep.	20 inches deep.	40 inches deep.	60 inches deep.
	Inches.						
Sept. 1870—Aug. 1871	27·55	34·9	34·2	21·1	65·1	65·8	78·9
" 1871 " 1872	29·02	33·4	32·4	28·4	66·6	67·6	71·6
" 1872 " 1873	30·66	46·8	44·6	39·2	53·2	55·4	60·8
" 1873 " 1874	21·69	25·2	23·5	16·6	74·8	76·5	83·4
" 1874 " 1875	30·74	39·9	41·4	33·5	60·1	58·6	66·5
Average . .	27·93	36·8	36·0	28·6	63·2	64·0	71·4
September	2·88	23·6	14·9	10·4	76·4	85·1	89·6
October	3·19	42·9	34·2	23·8	57·1	65·8	76·2
November	2·08	67·8	62·5	48·6	32·2	37·5	51·4
December	2·15	70·7	70·2	53·0	29·3	29·8	47·0
January	3·11	69·1	78·1	66·9	30·9	21·9	33·1
February	1·47	47·0	51·0	40·2	53·0	49·0	59·8
March	1·43	37·0	39·9	32·9	63·0	60·1	67·1
April.	1·76	14·8	16·0	12·5	85·2	84·0	87·5
May	1·91	11·0	12·0	9·9	89·0	88·0	90·1
June	2·77	17·3	15·5	13·0	82·7	84·5	87·0
July	3·47	28·0	29·7	25·1	72·0	70·3	74·9
August	1·71	0·6	0·6	0·6	99·4	99·4	99·4
Total	27·93						
Average	2·33	36·8	36·0	28·6	63·2	64·0	71·4

TABLE VI.—EXPERIMENTS at ROTHAMSTED, HERTS, ILLUSTRATING the INFLUENCE of VEGETATION on EVAPORATION. RESULTS RELATING to PERMANENT GRASS LAND.

——	Plot 3. Without Manure.	Plot 9. Mineral Manure and Ammonia-salts.	Plot 14. Mineral Manure and Nitrate of Soda.
	Cwt.	Cwt.	Cwt.
Produce of Hay per acre.			
Average 15 (or 13) years, 1856-1870 . . .	$22\frac{3}{4}$	$52\frac{3}{8}$	$57\frac{5}{8}$
Year of drought, 1870	$5\frac{3}{4}$	$29\frac{1}{2}$	$56\frac{1}{4}$
Deficiency in 1870	17	$22\frac{7}{8}$	$1\frac{3}{8}$
Manured more than unmanured in 1870 . .	..	$23\frac{3}{4}$	$50\frac{1}{2}$
Moisture in the Soils (dried at 100° C.) at different depths.			
	Per cent.	Per cent.	Per cent.
Samples collected, July 25–6, 1870. First 9 inches	10·83	13·00	12·16
Second ,, ,, ...	13·34	10·18	11·80
Third ,, ,, ...	19·23	16·46	15·65
Fourth ,, ,, ...	22·71	18·96	16·30
Fifth ,, ,, ...	24·28	20·54	17·18
Sixth ,, ,, ...	25·07	21·34	18·06
Mean	19·24	16·75	15·19
Estimated quantities of Water per acre.			
	Tons.	Tons.	Tons.
Total to the depth of 54 inches	1,546	1,346	1,221
Manured less than unmanured land . . .	..	200	325

TABLE VII.—DITTO DITTO. RESULTS RELATING to the GROWTH of BARLEY.

——	Barley Land.	Adjoining Fallow Land.[1]	Fallow Land more than Barley Land.
	Per cent.	Per cent.	Per cent.
Moisture in the Soils (dried at 100° C.) at different depths.			
Samples collected June 27–8, 1870. First 9 inches	11·91	20·36	8·45
Second ,, ,, ...	19·32	29·53	10·21
Third ,, ,, ...	22·83	34·84	12·01
Fourth ,, ,, ...	25·09	34·32	9·23
Fifth ,, ,, ...	26·98	31·31	4·33
Sixth ,, ,, ...	26·38	33·55	7·17
Mean	22·09	30·65	8·56[1]
Estimated quantities of Water per acre.			
	Tons.	Tons.	Tons.
To the depth of 54 inches	1,863	2,772	909[1]

[1] About 0·65 inch of rain had fallen ten days previous to the collection of the soils, and 0·10 inch three days before; and for several days since the heavier rainfall some soil had been thrown on the uncropped land, probably retarding evaporation. Hence doubtless part of the excess in the uncropped land.

TABLE VIII.—COMPOSITION of DRAINAGE WATER from PLOTS DIFFERENTLY MANURED; BROADBALK FIELD, ROTHAMSTED. WHEAT EVERY YEAR, COMMENCING 1844. NITROGEN as NITRATES and NITRITES, per 100,000 parts of WATER.

Dr. Voelcker's and Professor Frankland's Results.

Samples collected at different periods of the year in 1866, 1867, 1868, 1872, *and* 1873.

Plots.	—	Nitrogen as Nitrates and Nitrites, per 100,000 parts of Drainage Water.					
		Dr. Voelcker's Results.		Dr. Frankland's Results.		Mean.	
		Experiments.		Experiments.		Experiments.	
2	14 tons farmyard manure, every year	2	1·606	4	0·922	6	1·264
3–4	Without manure, every year	5	0·390	6	0·316	11	0·353
5	Mineral manure alone	5	0·506	6	0·349	11	0·428
6	" " and ammonia-salts (41 lbs. nitrogen)	5	0·853	6	0·793	11	0·823
7	Mineral manure and ammonia-salts (82 lbs. nitrogen)	5	1·400	6	1·477	11	1·439
8	Mineral manure and ammonia-salts (123 lbs. nitrogen)	5	1·679	6	1·951	11	1·815
9	Mineral manure and nitrate soda (82 lbs. nitrogen)	5	1·835	5	1·039	10	1·437

Mr. RAWLINSON, C.B., observed that it was interesting to have accurate reports of rainfall for a series of years, but it would be misleading if any engineer trusted to them without fully considering their import. Those returns showed that the fall of rain was local, and was largely modified by local conditions. In England and Scotland there was an annual variation of from 16 inches on parts of the eastern coast to 130 inches on parts of the western coast. He had been over and over again told (and had also read) that the seasons were changing, that felling of timber, land drainage, cultivation, and other works of man in various parts of the world had so modified climate as totally to alter its character. Looking at the great sources of meteorology, he utterly and entirely repudiated that notion. The great source of heat was the sun; the ocean was the prime source of evaporation; and the atmosphere which enveloped the globe received the vapour and conveyed it to different areas upon the surface. Man could not influence the heat arising from the sun; he could not diminish nor add to the area of the ocean in any perceptible degree; he could not control the atmosphere; consequently, as regarded the great features of meteorology, he was absolutely powerless to meddle with the excesses of drought or of flood. That felling timber over a limited area might influence the climate on that special area in ordinary times to a few degrees, he was not prepared to deny; that cultiva-

tion and land drainage did so was admitted; but these were the ordinary and moderate features of meteorology, and not its prime character. In his inquiries he frequently put the question, "Do you think there will be the excesses that we have experienced in former years?" and the reply almost invariably was, "We do not; we think that we shall never again have the floods and the excesses that we had formerly, because so-and-so has been done;" and during the time he was pursuing those inquiries in Yorkshire, a rainfall commenced, and went on unceasingly until on the 17th of November the flood rose 6½ inches above the line of a great flood which occurred in 1775, deluging the valleys of the Aire and Calder to a greater extent than the "oldest inhabitant" could remember; showing that there, at all events, anything that man had done during the last century had not modified that excess. It was true man had done something mischievously to add to it; he had abused the rivers, had accumulated refuse in their beds, and encroached upon their banks. It was a proper thing to get averages of rainfall or of temperature, but averages in themselves might be misleading. An average of rainfall could not entirely be relied upon by the hydraulic engineer: what he wished to know was the excess and the minimum. He must know the greatest power that he had to contend with in establishing his works; he must know the least volume of water that nature would give him, that he might provide for a sufficiency during times of drought. Many years ago, looking at the returns of dry years and of wet years in different parts of the world, he came to the conclusion that a rough and ready way of getting at the maxima and minima would be to add one-third to the average for the maximum, and to deduct one-third for the minimum. That, of course, was not absolutely correct, as excesses might vary both ways. A man might, however, go on amusing himself all his life collecting and storing facts and never come to a knowledge of their true use. With respect to practice, waterworks had been constructed and compensations (in water) stipulated for, based on averages of rainfall, which a dry year, or a series of dry seasons, proved to have been an error; the compensations could not be paid in water, and, consequently, had to be paid in money. Hence the warning—Do not depend upon averages. He could only compare Nature in her great operations to the beating of a pulse, or to the swinging of a pendulum. If the average rainfall, evaporation, or temperature were taken and drawn as a line having the maxima and minima plotted through a series of years, the alternations would be found to oscillate up and down much like the beating of a pendulum. Now, if the great source of

heat obeyed that law of oscillation, and he had no doubt but that it did, then there would be in the climate of the globe a variation of temperature, of evaporation, and of rainfall corresponding to it. Some persons asserted that it was possible to have a universally wet season and a universally dry season. As nature existed at present the thing was, however, absolutely impossible. No such thing could be known as a universally wet season over the entire surface of the globe, or as a universally dry season; but this was known, that in either hemisphere there might be cycles of dry seasons, and of wet seasons. The vapour from the ocean was raised with tolerable uniformity in proportion to the amount of heat, from the Equator to the Pole; it was carried up with some degree of uniformity into the atmosphere, but the precipitation was never uniform. The evaporation, say, of 10,000 square miles accumulated in the atmosphere, might be precipitated gently, or, more violently, over one-tenth, or even one-fifth of the area from which the evaporation had taken place. A wet season over portions of Europe might balance a dry season over portions of America, and so of larger or smaller areas. The flood flow of rivers varied in a degree that was hardly understood by some persons who yet imagined they knew something about it. There were, for instance, rivers in England having a flood rise of from 18 to 23 feet vertical over the summer level. The Ouse rose to that extent at York, and the Eden at Carlisle; while in some of the Scotch rivers the rise had been upwards of 30 feet. But what was that to the rise which engineers had to contend with in other parts of the world? In South Africa rivers rose vertically from 50 to 70 feet, and in some portions of Australia occupied by Europeans the rivers rose as much as 120 feet. In many parts of India, especially at the foot of the Himalayas, the rivers occasionally rose in the form of a bore; an enormous wall of water coming down as suddenly as a cataract, and woe be to the works of the engineer that were in its way if he had not foreseen and considered something of the effect of the volume of water that was to come upon his works. With regard to the velocity of water and its scouring effect, in the last return relative to Indian railways mention was made of a flood that swept down certain viaducts in Upper India, flowing at the rate of 40 miles per hour.[1] If ever such a flood came down at the rate of 40 miles an hour, he did not wonder at the viaducts giving way; but he was sure there must be a mistake in the statement.

---

[1] *Vide* "Report on Railways in India for the Year 1874–75." By Juland Danvers. Page 5.

With regard to the dry-weather effect in parts of England, he had known twenty continuous months when none of the rain that fell was available for a reservoir situated on the gathering ground. That feature must be taken into account, for when there was a minimum fall of rain, and the reservoirs were low and reducing, the rain might fall in such a form as to falsify the small volume measured in the rain gauge, making it from the surface of the ground *nil*. After two or three dry summer months, he found, upon an area in South Wales, that unless 2½ inches in depth of rain fell within six days, nothing came off to flow down the streams in the valley; and it could therefore easily be imagined that there might be a considerable fall of rain at intervals upon a parched and absorbing earth, which would not be available for water supply. Therefore, when waterworks were to be established to supply a district, a much larger source must be looked to than had sometimes been the practice. But, if waterworks were to be established where falls of rain such as were met with in India occurred, 300 inches falling within three months, and at times from 12 inches to 20 inches in a day and night, great care should be taken to put the embankments upon limited areas; or, by side channel, overflow, or bye-wash, to protect the embankment, in such a way that the vast masses of water liable to come down could not be brought to bear upon the works so as to destroy them. Thunder-storms, over any portion of the earth's surface, might pour down, on a limited area, a destructive volume of water. In England, rain had been measured falling at a rate of 4 inches per hour, and this even on the East Coast, with its average of 16 inches per annum. The laws governing the fall of rain, its re-evaporation, its percolation, and its flow over and off the surface, deserved serious study; and the Papers read and under discussion formed a good groundwork for the student, who would, however, never learn too much, as there were secrets in nature he could not know; but his knowledge, aided by experience, might prevent him committing egregious blunders. All men were liable to failures; but, if any bridge or bank was made safe on a second attempt, fuller knowledge and more care would have enabled the engineer to have designed and constructed an enduring work at the first.

The Rev. J. C. Clutterbuck said the valley of the Thames was subject to floods, on account of the masses of impervious strata from which the water was thrown off. The lowest lias clay formed the bottom of almost all the valleys in that part of the country running up in a straight line to Banbury, where there had been most serious floods last year; besides which, the upper lias clays

here and there cropped out. Those were the places, he conceived, in which water could be best stored. There were certain reservoirs which fed the summit-level of the Oxford canal, and he was informed that it had never been in want of water—nay, that in some of the dry seasons the managers had been able to accommodate the Grand Junction canal with some of the water. The valleys were particularly formed there to favour the storage of water. Interposed between the lower lias and the upper lias clay was the marlstone, which yielded a certain quantity of water; and it was by excavating into the lias that the water was stored. Beyond that, just within the watershed of the Thames, to the west, there was a remarkable district, in which the water was lost. The late Mr. James Simpson, Past-President Inst. C.E., was employed to ascertain the reason why the water delivered from the springs above was diminished ere it came into the Thames. With reference to the other part of the watershed, and its capabilities for storing water, there were under the chalk hills a number of considerable reservoirs, which he believed might be increased, all more or less fed by perennial water issuing from the foot of the chalk which rested on the Gault clay. He had little confidence in the possibility of storing water in the lower part of the valley of the Thames, except in the river itself; and there might certainly be a great increase of water in the bed of the Thames, if it was properly dredged. Of the most remarkable floods that had occurred, there was one as far back as 1734, but the first great flood on record was in 1774, which swept away the bridge at Henley-on-Thames, and was almost identical with the flood of November 1875 in height. The great flood of this century was on the 27th of January, 1809, which swept away many bridges, and in 1821 there was another flood, but there was no record of the absolute amount of rain that fell to produce those floods, except that the first was caused by the melting of snow. He believed that when autumn came it required at least 3 inches of rain to replace the evaporation, and until that which had been evaporated was replaced no water could find its way to the lower part of the earth, or be thrown from its surface. He had measured a great number of wells for more than thirty years, and found that they were affected by the amount of rainfall; the same amount of rain produced, as far as he could judge, the same effects upon the lower receptacle of Dalton's rain gauge. Mr. Symons's record of the rainfall about Oxford showed the results in July, October, and November, 1875. In July an immense quantity of rain fell in some parts of the watershed of the Thames: 3·11 inches in one day at Cirencester, and in two days there were

nearly 3 inches at Banbury; and taking the other rainfall, which would affect the July flood, he found there were about 4·32 inches at Cirencester and 4·60 inches at Banbury. That was a fair calculation of the quantity of water it took to make the July flood. That flood did not come up with a sudden rush, but gradually, and it went up to about 3 feet 10 inches at the place where he noted the height of the water, and to 4 feet 6 inches at Teddington; but the quantity of rain was as great as it was in any of the floods which followed. In the early part of October there was a fall of rain of 2·13 inches at Cirencester and 3·25 inches at Banbury; that flood rose higher than the previous one, though, as far as his calculation went, there was less water. But in September there had been a considerable amount of rain, enough almost to replace the evaporation of the end of July and August, and the flood rose to 5 feet 1 inch instead of 3 feet 10 inches, and to 4 feet 9 inches instead of 4 feet 6 inches. The second flood in October was caused first by 1·15 inch at Cirencester and 1·19 inch at Banbury. The total rain causing the flood was 3·44 inches for Cirencester and 3·09 inches for Banbury, less than the water which caused a much smaller flood in July at the same place. Then came the last and greatest flood of all, caused by a total rainfall of 4·44 inches at Banbury, and 4·54 inches at Cirencester, and rising to 8 feet 5 inches instead of 7 feet 3 inches at Clifton Hampden, and to 10 feet 2 inches instead of 8 feet 8 inches at Teddington. Here, then, was a progression of floods not altogether in proportion to the quantity of rain falling, but due to the conditions of the earth on which it fell; and if great care was not taken, calculations of this sort would lead astray—if averages and quantities of rain were considered without the circumstances under which the rain fell and the circumstances of the earth which received the rain. There was a well which he was in the habit of measuring against these floods and against the rainfall. The first great rainfall, which at Cirencester was 3·11 inches, raised the water in the well only about 1 inch, showing that the rainfall had only just replaced the water that was evaporated. The well was 40 feet deep, in rubble, and was a fair gauge. Up to the 11th of October there was just enough rain to saturate the soil, and when the flood was beginning to subside, after it had got to its culminating point, the well began to rise. It was a great mistake to suppose that the chalk was long in answering to the rainfall. It was a long time before the whole of the evaporation was replaced, but immediately the rainfall had saturated the soil, the water-level in the well rose rapidly, in two days 5 feet, and then fell, for this reason;

there was an increased pressure of the column of water in the earth, and new sources by which the water could escape. The water went down and rose again with the next flood, the height being 2 feet more at the time of the culminating of the flood in November. His object was to show that allowance must be made for evaporation, but as soon as the water lost by evaporation was replaced, the well would at once indicate it.

Mr. MERRIFIELD observed that the lower portion of the Thames was rather singularly protected by nature from anything like unnecessary or unusual disaster from floods. The normal condition of a protected river was the summer trough, with an inundation area, either without banks, as in the case of some natural rivers surrounded by large marshy flats, or with banks at a considerable distance from the river, allowing a considerable inundation area over which the river could expand itself. He knew no river that gave greater natural facilities for that security than the lower valley of the Thames. The outcry lately raised was not one arising from anything that engineers could do, but was simply that of a man who had built his house in a place where no house ought to be built, and then asked to be preserved from the ordinary floods that came down the river channel. This outcry, chiefly coming from the lower parts of Reading, Windsor, and that part of Surrey immediately bordering on the Thames, seemed to arise from an idea that engineers could save from floods low-lying localities which were most peculiarly exposed to them, and which were evidently meant by nature to take the floods. Of course the answer was, "If you will build in such a place, you must be your own insurers against damage, and you must either raise all the injurable parts of your houses to a sufficient distance above the flood-level, or you must take the consequences." When a population of three-quarters of a million had chosen to fix itself in that way, engineers would provide what protection they could, but palliatives, and palliatives only, were what the case would admit of. Another important question was the provision and storage of wholesome water. Mr. Symons had quoted some remarks of his made at Bristol, to the effect, that comparatively pure and healthy commons were being gradually replaced by highly-cultivated fields, off which clean water could not possibly flow. No doubt increasing care was required both in the storage, selection, and in the preparation of the water to be drunk. If people were to be frightened at the possibility of having a single animalcule or a single germ of disease in their water, it was clear they must not venture upon touching any that

had not been distilled. That, however, was an absurd state of things. The danger arising from the increasing degree of contamination would no doubt be enormous, but for the fact that while these lower forms of life reproduced themselves at an almost immeasurable rate, yet the destruction of embryonic life was so enormous that it kept equal pace, the result being that a very small proportion presented themselves in a form to do injury. This waste was well exemplified in the case of the male fern, the five or ten million separate spores of which did not, on an average, result in the growth of more than one, two, or three male ferns a year that fructified; for it was well known that ferns, although they lived long and bore an enormous quantity of spores, really increased very slowly except under the most favourable circumstances, and then not with any great rapidity. The lower forms of life were subject to much the same laws. Very few germs would bear keeping without losing their powers of development, and the general destructive influences were abundant. The result was that few came to any practical development, compared with the potential number that there would be if each one survived. He suggested that water should be carefully selected, not merely as to its source, but also as to the use to be made of it; for nothing could be more monstrous than complaining of the difficulty of supplying London with pure water, whilst the water supplied for drinking was all the time being used for every imaginable purpose—from putting out fires to flushing water-closets, the contamination from which sometimes found its way to the table. He referred to the fact that the process of distillation was used in a great many countries where it was difficult to get water, and where coal was much dearer than in England, and he observed that there were evidently some parts of this country where such a process might be not only useful, but economical.

Mr. Homersham said the Author of the first Paper had conclusively shown that there could be no hope, at a reasonable outlay, for the mitigation of floods by the construction of flood-water reservoirs, or, as they might more properly be called, artificial lakes, in the valley of the Thames. The drainage ground of the Thames above Hampton occupied 3,676 square miles, and he had properly put it that 1 inch of rain flowing off this area would fill a reservoir containing 53,375,000,000 gallons, equal to 8,540,000,000 cubic feet. He also added that the construction of a lake or lakes of this capacity would entail an expenditure of £5,000,000. Mr. Homersham had checked the estimate, and considered the cost under, rather than over, estimated. If it were

wished to store 3 inches of rain over this surface, £15,000,000 must be expended. This would require a lake or lakes 40 feet deep and $7\frac{3}{4}$ square miles in area. That was a great depth for such a lake; even in selected sites, in suitable valleys, such as those for the supply of Manchester and other places, an average depth of more than 35 feet had not been obtained. Supposing this area of land, $7\frac{3}{4}$ square miles, covered with water in the valley of the Thames—the lakes sometimes full and sometimes empty—where every flood carried with it fallen leaves in the autumn, fallen blossoms in the spring, débris from the sides of the hills, manure from cultivated land, &c., the result would be that a large quantity of mud would be formed in the lake, and soon cover the bottom. As the sides of such lakes were likely to be exposed in the summer, miasma would arise from this putrefying filth and mud. If smaller lakes were to be made to store flood water, to be added to the flow of the river in droughts so as then to increase the flow, what would be the quality of the water? The temperature of the water in the valley of the Thames was high in summer and autumn, and, according as water was higher or lower in temperature, so it took more or less organic matter in solution, and as the result the water would get filled with much decomposing organic matter, and when let down into the river would make the water more than ever unfit for human consumption. The Author had alluded to water from wells sunk in the chalk as a source of supply. The area of the watershed of the Thames at Hampton was about 3,600 square miles, and there was about the same area of thinly covered chalk within a moderate distance of London. In the south-east of England altogether there were 5,300 square miles where the chalk appeared at or near to the surface. An inch deep of rain over this area, absorbed as it was in that formation as fast as it fell, would yield something like 150,000,000 gallons a day for every day in the year, so that the supply to be thus obtained was practically illimitable. The Author stated large quantities of nitrates were found in the chalk well water of Watford and other places. Now he had had water from unpolluted chalk wells in many situations analysed frequently, and found that it contained nitric acid in the proportion of $\frac{1}{5}$ to $\frac{3}{4}$ grain per gallon, and that could not be considered a large quantity. It was stated that M. Béchamp, a well-known French *savant*, had once said that there were living organisms in the chalk. It was true in 1867, or 1868, M. Béchamp gave out that he believed he had made such a discovery; but at the present time it was well known that the supposed discovery was

a mere myth, and that such things never really were found in chalk of a normal quality, and no one at the present time believed in it. Then with regard to filtration, it was said that the better class of domestic filters would filter Thames water and make it good. He entirely dissented from that view. He had had water that had been first filtered by a London water company, afterwards passed twice through a Lipscomb filter, and then the microscope showed that it contained living organisms. Water companies filtered the water through a layer of sand, the filth being arrested upon the surface: in the summer, the temperature of the river water being about 70° Fahr., the organic matter so arrested decomposed on the surface of the sand, and the water, which had to pass through this matter before it could reach the surface of the sand, took the decomposing matter into solution, and so was really little better, as far as wholesomeness went, after passing through the sand than it was before, though it was made somewhat clearer. Again, the material through which the water passed had the interstices between its pores water-logged. But in spring-water, derived from the rain that fell over chalk or indurated sand hills, the rain that fell in one year was probably fifty or a hundred years descending through the body of the strata before it reached a saturated water level. The chalk held, not only some atmospheric air in its minute pores, but, by means of capillary action, a large quantity of water was also diffused through it; as soon as the pores of a top layer of chalk were filled to a certain extent with water, it passed down; thus, if water was poured on the top of a thin stratum of chalk, in descending it would force down some of the water in the lower portion. Water purified in this manner when passing through the chalk was brought in contact—especially with every alteration of the barometer—with changed atmospheric air, and this over a long series of years. The result was that the whole of the organic matter was oxidised and much of it changed either into nitric acid or carbonic acid. The water was thus rendered pure and perfectly free from organic matter, attained the average temperature of the climate and became well aerated, absorbing a large quantity of air and oxygen gas and holding it in solution. That was the difference between artificially filtering water through a stratum of water-logged sand and through the aerated pores of a chalk hill.

In the second Paper the results had been given of two gauges, one gauge filled with selected soil, having grass on the top of it, and the other filled with sand. With the gauge filled with sand, about 20 inches were obtained out of 22 inches depth of rain falling

in the year, and this amount was got under most adverse circumstances, because the gauge was filled entirely with sand, so that when heavy rain fell, some of the water could hardly fail to flow over. It was true, Mr. Greaves said nobody had seen it so flow over, but in heavy and sudden rains no one was likely to be watching.

Mr. GREAVES said he had watched in the heaviest rain to see whether water ever lay on the top, and had never seen it.

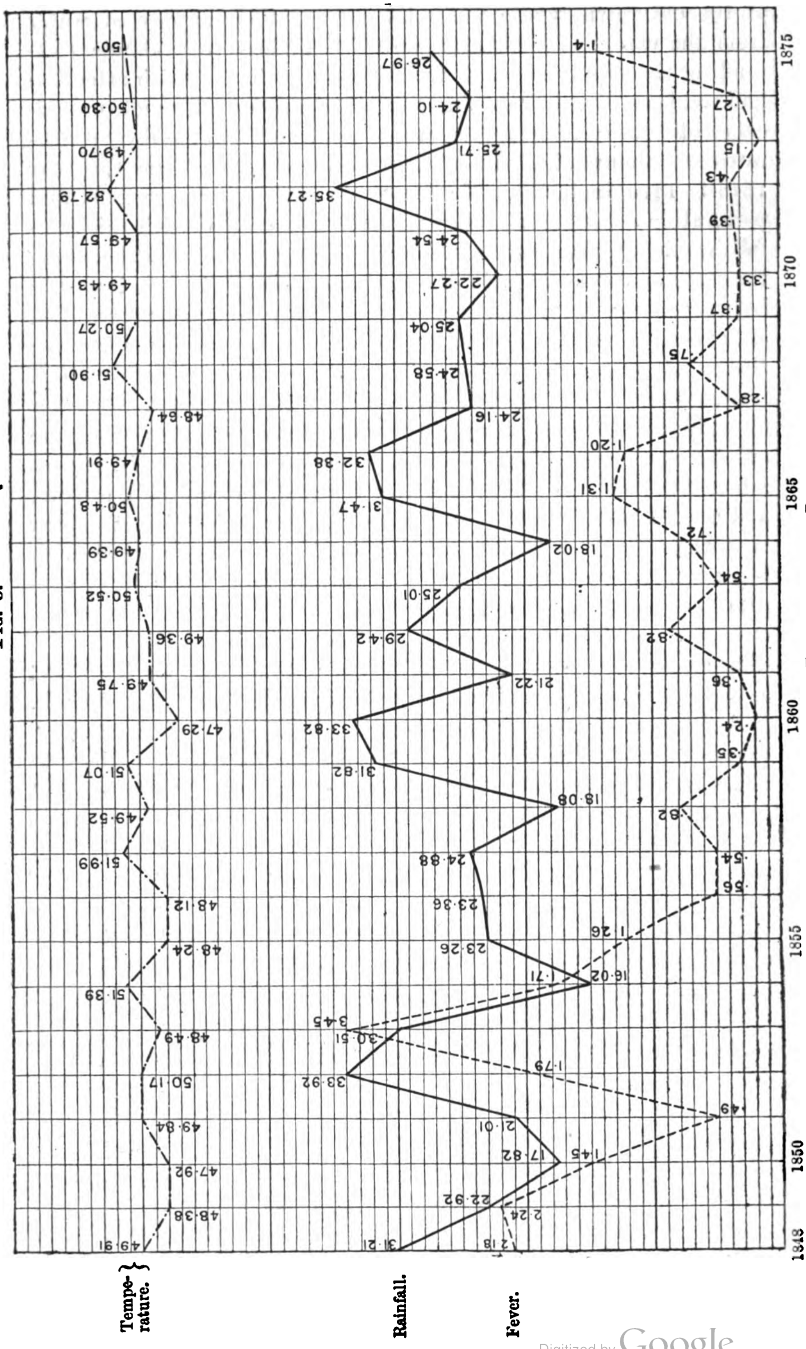
Mr. HOMERSHAM said the meeting would take note of the statement; he himself did not put much confidence in it. Dr. Dalton, when he made the gauge called by his name, kept the surface of the soil somewhat below the top of the gauge, and put in a pipe just level with the surface of the soil and a vessel to catch any water that overflowed, and he gave the result not only of what percolated down through the soil, but of what was thus caught. In this case the overflow pipe used by Dr. Dalton was wanting: and his own opinion was that if Mr. Greaves had had such a contrivance the gauge would have shown a certain amount of water flowing off; and certainly the soil gauge must have done so, because the quantity of water that flowed off the surface of a loamy soil in heavy summer rains was large. Mr. Greaves had proved that in the middle of the summer the soil gauge showed no water passing through and no water flowing off the surface, and then it was taken for granted that all the rain falling was evaporated. He wished to know whether any one believed that, on the 15th of July, in those heavy floods, the whole of the water that fell upon the surface of the soil gauge was evaporated—that no water went through the gauge, and that none overflowed? That water in abundance flowed off the surface of the ground was proved because it came down the rivers in floods; therefore there must have been something very dissimilar between the surface of the natural ground and that of Mr. Greaves's gauge if water did not overflow the top of it and no water sank through it. This question was much more important than at first appeared, because the Author endeavoured to deduce, from gauges, erroneously styled Dalton's gauges, that deep wells were not supplied with large quantities of water percolating from the surface; but taking the results given by the sand gauge, it would be seen that nearly all the rain falling on porous soil passed down through it.

Mr. BALDWIN LATHAM remarked, in reference to the remarkable coincidences disclosed, in his opinion, by the, unfortunately, not unfrequent outbreaks of epidemic fever in Croydon, that that portion of the parish which alone had been subjected to these outbreaks of fever drew its water from wells located in the centre

of the old town, while the wells derived their supply of water from the chalk. The results showed that there were dangers attending the supply of water from a chalk well, to which attention had not been directed. In Fig. 5 (p. 74) were shown the meteorological conditions of temperature and rainfall, and also the fever death-rates per thousand of the inhabitants at Croydon, from the year 1848 to 1875, inclusive. Mr. Greaves's rainfall observations and percolation experiments, when taken in conjunction with this rainfall, would supply some data by which to judge of what had been the state of the springs in the chalk at, and during the intervals between, the periodic outbreaks of fever. Fig. 6 (p. 75) represented an experimental apparatus, executed in glass, to illustrate the theory of wells, and to demonstrate the conditions under which fever occurred in Croydon. It had been noticed that, whenever an epidemic of fever prevailed there, it occurred either when the subsoil water under the town was unduly elevated, or in a year when there had been a remarkable deficiency of rainfall, causing a diminution of water in the springs. It might almost appear that those two conditions were opposed, yet when viewed with regard to the question of procuring water from wells those conditions were coincident. The elevation of the surface water outside a well, and the lowering of the water in a well when the diminution of the springs took place, were identically the same, as he showed by ocular demonstration upon the model, Fig. 3. With regard to the assertion that it took about eighty years for the rainfall to percolate through the chalk into the well, the late Mr. F. Braithwaite, M. Inst. C.E., and Professor Prestwich had given their opinion, that there was little percolation through the chalk itself, that filtration was slow, that the water moved through the cracks, clefts, and fissures, and through or under layers of flints, and that only the free water of the chalk was available in wells for the purposes of water supply.[1] With regard to the flow of bourne water, he hardly thought the solution of the real cause had in every case been ascertained. It was generally supposed the bourne water was due to the elevation of the water-line in the chalk, and this was correct for some bournes. The appearance of other bournes rather pointed to the fact that the Upper Chalk was more fissured and broken up than the Lower Chalk, and that rain moved more rapidly through the Upper Chalk, than in that portion of the strata which was compressed by the other strata lying upon it; that when water percolated through the Upper and fissured

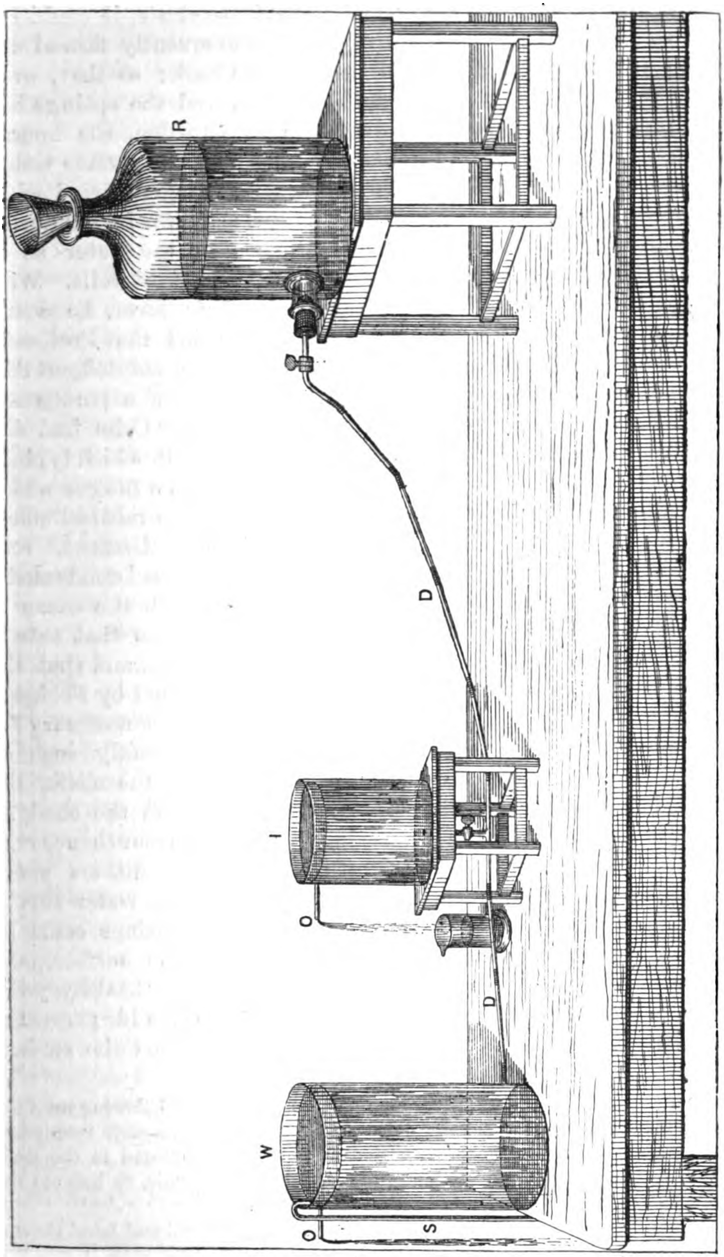
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., pp. 73, 77.

Fig. 5.



Croydon.—Fever, Temperature, and Rainfall.

Fig. 6.



MODEL EXPLANATORY of the THEORY of WELLS, showing how surface impurities may enter the springs.

W, well. I, intermediate spring. R, reservoir. D, duct. S, siphon. O, overflow.

Chalk, and entered the lower and more dense strata, it could not pass so freely to the deep springs, and consequently flowed out again at the lower outcrop of the Upper Chalk;[1] so that, even when the water had overflowed the surface, and the springs had not reached their maximum discharge at Croydon, the bourne water entered the chalk, taking with it the impure surface water, sewage, &c., and fever prevailed. The same thing occurred when the springs were low, and pumping at the waterworks exhausted the springs, and caused such a depression of the water as to enable impurities from the surface to enter the wells. With regard to what should be the cause of enteric fever, he would draw the attention of the Institution to the fact that Professors Pettenkofer and Buhl, of Munich, some years ago, pointed out that typhoid fever was coincident with the conditions of a porous soil having a watery subsoil. More recently, Professor Cohn had discovered, in the neighbourhood of Breslau, a district in which typhoid was never absent, that the well waters contained a fungus which he had called *Crenothrix polyspora*. A report of the medical officer of the Privy Council, recently presented to Parliament,[2] contained the clinical observations of Dr. Klein, who had conducted a number of post-mortem examinations, to ascertain the cause of enteric fever. Dr. Klein had come to the conclusion that enteric fever was, like small-pox, due to a vegetable germ, and that the germ appeared to be identical with the fungus found by Professor Cohn in the well waters of Breslau. The conditions necessary for the development of low fungoid growth were exactly such as existed at Croydon, porous damp soil covering of the chalk, the chalk being much fissured, and springs flowing from the chalk at all ordinary times into the overlying gravel, and from thence running as the river Wandle. These were the conditions under which impurities might readily be passed into the water supply of the district. Only at those times when the springs could be affected by impurities passing into them from the surface, had fever prevailed at Croydon; moreover, extremely healthy years were those years when the springs were strong, and prevented the entry of any back flow of impure water from the surface.

---

[1] In corroboration of this view, a bourne was now (May, 1876) flowing out of the chalk hills in the Caterham valley, at the rate of 630,000 gallons in twenty-four hours, and yet at a lower point in the valley it all disappeared in the chalk again. This bourne rose and fell within a distance of 1 mile, or between the Rose and Crown and Kenley railway station.—B. L.

[2] *Vide* Reports of the Medical Officer of the Privy Council and Local Government Board. New Series, No. VI., p. 80.

While some years of high rainfall were fever years, others had been extremely healthy. The percolation experiments of Mr. Greaves, Mr. Evans, and others, however, gave a clue to this apparent anomaly, and showed that the fever had a direct connection with the state of the springs, and that rain only influenced the result so far as it affected the springs. As an example, the rainy years 1859 and 1860 were healthy; the reason being that, although the Bourne flowed in 1860 in the Caterham valley, the discharge did not exceed 1,500 gallons per minute, and it never reached the town of Croydon, all the water disappearing in the chalk in the neighbourhood of Caterham Junction railway station. At this time (March 1876) the springs of Croydon, beyond the water pumped, were strong, flowing at the rate of 3,500 gallons per minute. If the water-line under the town was elevated, and the springs were not full, then impure water would enter them. This was shown by the flow of the Bourne: in 1853 and 1866, the latter year being one of very copious rainfall, the bourne commenced to run when the springs were comparatively low, and flowed over the surface, elevating the level of the subsoil water. During the outbreaks of enteric fever in Croydon, that portion of the district supplied with Thames water almost escaped. It had been proposed to shut out impure water from the wells by iron tubbings; but it had been conclusively shown that such means would not secure the end sought,[1] for it was not necessary for the water to percolate through the sides of the well itself; it might pass down at any distant point into the spring, and the simple lining of a well would not prevent the percolation of impure water into the springs. Mr. Latham then showed, by the model, the conditions under which water could enter springs. If water was taken out of a well as at W, which was supplied from distant hills represented by R, the water flowing through a duct, D, impurities might be drawn in at an intermediate point, as at I. For example, if the water in the vessel at I was elevated, it would pass back into the water of the well W, although the internal pressure in the duct were operating against an external pressure; but as the internal pressure was limited by the frictional resistance, a sufficient elevation of the water surface at an intermediate point overcame the internal pressure, and the direction of the flow was reversed. The same thing would happen if the distant spring was lowered, frictional resistance being about the same quantity for high or low springs; the internal pressure diminished,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 42 *et seq.*

with the fall of the springs, to that at the intermediate point I. If the vessel I contained impure liquid, it would fall back with the general fall, and, consequently, would pass into the vessel W. It was under these two conditions—first, the elevation of the subsoil water under the town of Croydon, which no doubt communicated with the springs; and, secondly, when the spring had been exceptionally low, that impurities passed into the water supply, and so had produced the epidemic outbreaks of enteric fever which occurred at uncertain intervals of time.[1]

GAUGINGS of the BOURNE at CROYDON.

(Compiled by Mr. Baldwin Latham.)

Date.	Quantity of Water flowing over surface, Brighton Road end of Bourne Culvert.	Quantity of Water flowing out of Bourne Culvert at Croydon.	Quantity of Water collected in Subsoil by Bourne Culvert, partly Surface Flow and partly Spring Water.	Observer.	Remarks.
	Cubic feet per minute.	Cubic feet per minute.	Cubic feet per minute.		
Spring, 1853 .	Not known.	2,111	Not known.	Braithwaite.	Enteric fever year.
„ 1858 .	..	80	80	Fenton.	„ „ „
Feb. 1861 . .	None.	560	560	„	Healthy year.
„ 20, 1866.	1,299	1,920	621	Latham.	Enteric fever year.
„ 27 „ .	1,800	3,212	1,412	„	
Mar. 6 „ .	1,600	2,505	905	„	
„ 13 „ .	1,428	2,550	1,122	„	
„ 20 „ .	844	2,168	1,324	„	
„ 27 „ .	380	..	380	„	
April 3 „ .	248	1,364	1,116	„	
„ 10 „ .	120	1,152	1,032	„	
„ 17 „ .	40	1,026	986	„	
„ 24 „ .	None.	900	900	„	
May 1 „ .	..	846	846	„	
„ 8 „ .	..	816	816	„	
„ 22 „ .	..	647	647	„	
„ 29 „ .	..	528	528	„	
June 5 „ .	..	622	622	„	Fever no longer epidemic.
„ 12 „ .	..	512	512	„	
Feb. 17, 1873.	228	1,089	861	Walker.	Healthy year.
Mar. 2 „ .	129	1,195	1,066	„	„ „
„ 8 „ .	42	1,024	982	„	„ „
April 1 „ .	..	864	864	„	„ „
March 1875.	None.	None.	None.	„	Epidemic of enteric fever.
„ 5, 1876.	..	312	312	Latham.	Enteric fever no longer epidemic.
April 2 „ .	..	403	403	„	

[1] The following paragraph appears in Dr. Buchanan's report to the Local Government Board on an epidemic of enteric fever at Croydon in 1875, dated

Mr. SHELFORD observed that the great Fen rivers were the Ouse, the Nene, the Welland, and the Witham. For the purposes of the discussion they were very similar, and he would confine his remarks to the one with which he was most familiar, the Nene. It rose in Northamptonshire, and passed by Northampton, Peterborough, and Wisbeach to the sea. Above Peterborough it traversed an ordinary upland district, oolitic in character; below Peterborough it passed through fen land to a point a little above Wisbeach, and from thence to the sea through what was locally known as salt marshes—a deposit thrown up by the action of the sea from time immemorial, and lying a few feet above the fen land. The consequence was that the fens had been subject to the action of extraordinary tides, as well as to a deluge of fresh water from the uplands. The drainage area of the Nene above Peterborough was about 600 square miles. The greatest flood through Peterborough Bridge was about 8,000 cubic feet per second, equivalent to ½ inch rainfall in twenty-four hours over the drainage area above Peterborough. This was remarkable, inasmuch as Mr. Symons had ascertained that more than 2 inches of rainfall in twenty-four hours had fallen over the whole of that watershed; and he was under the impression, though there was no record to show it, that that was not by any means the maximum, and that there had been rainfalls approaching 3 inches. The quantity of water in relation to the rainfall appeared very small, but it was a large quantity in reality, and the Fen men had dealt cautiously with it; the more so because at Wisbeach Bridge the sectional area of the river was smaller than at Peterborough. The sectional area at Wisbeach Bridge in old times was 796 square feet, whereas at Peterborough it was 1,856 feet. In embanking the Nene and other Fen rivers, care was taken to leave a wide margin, in fact to form large basins or reservoirs, locally called washes, in which the floods might expend themselves and find their way quietly down to the sea. One of these washes now existed immediately below Peterborough; it was 12 miles in length, and had an average width of ½ mile. The surface was in great request in summer time for pasturage. Its level coincided with ordinary high water. The Wash might be taken to be 1 per cent. of the area draining into it. An ordinary flood filled the Wash to the depth of 5 feet, and an extraordinary flood to the depth of 7 feet, or more. The volume in the Wash, due to the 7-feet flood, would be about

April 18, 1876: "I fail to find any evidence to support the view that the general water supply as it leaves the wells and reservoirs of the town has been at fault," p. 14.—SEC. INST. C.E.

two days' flow from the drainage area, or 1 inch depth of rainfall. That reservoir had always been sufficient. The banks had occasionally burst, from undue pressure or bad construction, but it had never overflowed. This, in his opinion, proved that a storage of a depth of 1 inch rainfall was sufficient for such a river, which was somewhat similar to the Thames; and that the statement of Mr. Symons, with regard to the necessity of providing for 3 inches, was scarcely justified by the experience of engineers. He did not, however, wish it to be supposed that he approved of such a reservoir as that existing upon the Nene and some other Fen rivers. He believed that the force of the floods was increased by such reservoirs. When that to which he had alluded was once filled, the flood-level at Peterborough was transferred to a point 12 miles lower down, and the gradient between the flood-level of the land water and the low water of the sea was increased in proportion to the amount that the distance was diminished, namely, 12 miles out of 32 miles. In fact, in 1852, when the greatest flood on record in that district occurred, the rush of water when the reservoir became full did a great deal of damage. Since 1852 obstructions had been removed, under the direction of the late Mr. Rendel, Past-President Inst. C.E., and Mr. Fowler, Past-President Inst. C.E., and the sectional area of the bridge at Wisbeach was now 2,500 square feet instead of 796 square feet. In 1875, when the rain which Mr. Symons recorded fell, he believed no inconvenience was suffered from the discharge of fresh water; some damage, however, was anticipated from the extraordinary high tides which occurred there at the same time as in London, but due to totally different causes. It was to the removal of obstructions that engineers must look for a remedy, and floods from any river should be discharged into a full tidal basin rather than into reservoirs artificially constructed. In the Paper which he read before the Institution five years ago, on the Outfall of the Humber,[1] he showed that although that river drained a fifth of the whole of England, 10,500 square miles, a rainfall of ½ inch over the whole of it, which would produce an excessive flood, would only be equal to one-fourth of the tidal capacity of the Humber, and that its effect on the outfall was really not felt. He was far from saying that the proportion would be the same in the Nene or other rivers; they would no doubt vary, but he submitted that the tidal capacity of the rivers on the English coasts was always sufficient for the purposes of storing any floods that might come down from the uplands, if they were

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 472.

properly used. The difficulty, however, was in reconciling two conflicting interests, which were found almost invariably at the point of junction between tidal water and fresh water. On the one hand there was the navigation, which required tidal water of some depth, and on the other hand the landowners objected to tidal water, and above all things to salt water. Fortunately, a remedy for that had been found in the Fen districts. The free tide had been permitted to have its full swing, and by that means navigation had been improved, and also the drainage by lowering the low-water level; at the same time the fresh-water basin had been tapped above the tide, and the fresh water had been led down by a separate channel to the district requiring it. He was much mistaken if the remarks he had made with regard to the Fen rivers were not applicable to many others, the Thames not excepted. In any case, with regard to the storage of floods, he ventured to think that the use of any reservoir other than that which nature had provided would be a great mistake, and a retrograde movement in the science of engineering.

Mr. Dines said the maps clearly showed the local character of the rainfall. He thought the storage of rainfall was much neglected, and not attended to as it ought to be by private individuals. He believed that sufficient rain water fell upon most dwellings in this country to supply the inhabitants, if they would only use a little care and economy. It had been his lot to live and build in places where no water but rain water could be obtained. He began by making tanks that would hold about 1 gallon for every superficial foot of building; he soon increased the amount to 2 gallons, and he had little doubt that 4, 5, or even 6 gallons of rain water might occasionally be collected for every superficial foot of surface in the buildings. He was pleased that Mr. Greaves had given the details of his experiments with regard to evaporation, which he believed were the only ones that supplied anything like an approximation to the actual facts. He was strongly of opinion, however, that the total assigned was some inches below the true amount. If the surface of the water, or of any other body covered with moisture, was warmer than the dew-point, evaporation ensued; if colder, condensation took place.[1] But there was another important point, namely, the amount of wind; and it was evident that in a gauge similar to that exhibited, the wind could not have full play, as it would in the case of a large body of water, so that it would give less evaporation.

---

[1] *Vide* Proceedings of the Meteorological Society, vol. v., p. 201.

In experiments he had tried some years ago, he used a gauge rather smaller than that of Mr. Greaves, only 8 inches in diameter. In the one that was kept full there was an evaporation 50 per cent. greater than that in which the water was 3 inches below the rim. He did not wish Mr. Greaves to alter anything, but he should be glad if he would get another vessel, and keep it as full of water as possible. There would, of course, be difficulties to contend with from the in-splash and out-splash of the rain, but he would get sufficient observations to correct (if correction were needed) the experiments he had already made, and make them of still greater value. The evaporation, like the rainfall, no doubt differed much in different places, but, taking the average, it was evident that it must be equal to, if it did not exceed, the rainfall. Little was known as to the amount of moisture floating in the atmosphere, but it might be fairly assumed that some time within the last few years it was exactly the same as now; and if so, all the rain that had fallen since that time must have been previously evaporated, and the one must equal the other. Mr. Greaves had shown that evaporation from the ground was less than that from the water. Mr. Dines had come to the same conclusion five or six years ago. Excepting mountain ranges, the rain, as far as was known at present, fell equally upon land and sea; therefore evaporation must be equal to, if it did not exceed, the rainfall. He had erected a rather large tank, and had been observing evaporation day and night, and sometimes every hour, during the last twelve months. The difficulties were almost insurmountable, and he began to think that the question would never be decided until ½ acre or 1 acre in the midst of a large reservoir was fenced in. The interesting nature of the question in a great measure compensated for the difficulties that were met with. With regard to the remark as to the condensation on sand and on water, the water being increased beyond the rainfall, he had himself noticed the same circumstance, and he believed a larger deposition would have been found upon the grass than upon anything else. The old philosopher of Selborne was puzzled to know where the water came from that filled the ponds upon the chalk hills, and it was a puzzle still. A great amount of condensation took place upon trees. Some time ago he had thought that little condensation took place upon water, but he now began to alter his opinion. The amount deposited as dew upon the surface of the earth had been estimated as 5 inches in the last edition of "Wells on Dew," but this was uncertain.

Mr. Taunton thought some facts in regard to the sources of

the Thames in the Cotswold district might be of interest in connection with the subject under discussion. He had kept careful records of the rain, extending over thirty years, and had had access to the records of the Thames and Severn Canal Company, which contained an account of the springs supplying the summit level of the canal over a length of 9 miles, as well as to the records of wells in the gravel bed at Cirencester, kept by himself and by Mr. Brown, a careful observer in the locality. The rain in the district ranged from 20 inches in 1854 to nearly 50 inches in 1852. A great deal had been said as to storage reservoirs in the valley of the Thames and above; but he thought he should be able to show that Nature had provided a store reservoir in the Cotswold Hills, in the loose rocks of the great and inferior oolites. In the gravel bed under Cirencester the level of the water varied as much as 8 feet. In reference to that subject, he wished to say a few words on the question of percolation. In 1863 a Paper was read by Mr. Clutterbuck, and a report was brought before the Institution by the late Mr. Simpson, Past-President Inst. C.E., from which it appeared that there was a great loss of water in the Churn, after it left the lias.[1] Having a volume of 320 cubic feet per minute 7 miles from its source, this gradually decreased to 45 cubic feet. This was due to percolation in the tributaries, and to actual loss in passing the fissured, broken rocks of the inferior and great oolites. In the Stroud river, flowing in a different direction, he had observed a remarkable circumstance bearing on the subject of percolation. The river Frome flowed for about 7 miles to Chalford; and when he last gauged it (at a time when it was in an ordinary condition) he found that above Chalford only 2,000 gallons a minute came down, but within $\frac{3}{4}$ mile the amount increased to 10,000 gallons, an increase due to the extraordinary springs in the neighbourhood. One of those springs gave 400 gallons a minute, and it was nearly the same in the short-water time. This showed the great amount of percolation in the Cotswold country through the fissured subterranean channels. The short-water flow of the Frome in summer was about 3,000 gallons a minute, due to a rainfall on an area of about 25 square miles, which would account for nearly 5 inches of rainfall—not quite 28 per cent. (as given by Mr. Greaves) of the total quantity, but, for a few springs alone, 17 per cent. of the total quantity. It had been formerly thought that the great quantity of water lost from the Churn got under the fuller's earth and escaped altogether from

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 359.

Rainfall Observations made by Mr. Thomas C. Brown at Further Barton, Cirencester, 2 miles from Thames Head. Gauge 400 feet above sea-level.

—	1815.	1846.	1847.	1848.	1849.	1850.	1851.	1852.	1853.	1854.	1855.	1856.	1857.	1858.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Jan.	1·90	4·65	2·77	1·22	1·92	2·01	4·05	5·70	4·10	2·98	0·43	3·35	3·03	0·60
Feb.	1·00	1·40	2·40	4·05	1·75	2·03	0·85	1·70	1·05	0·96	1·25	2·10	1·55	1·00
Mar.	1·30	1·87	1·80	3·20	0·90	0·91	4·60	0·50	1·00	0·63	2·64	1·58	1·95	0·90
Apr.	1·90	3·65	1·58	3·50	3·10	4·33	1·13	0·70	2·56	0·25	0·60	3·33	2·60	5·25
May	2·50	2·21	2·30	0·45	3·35	3·50	1·45	2·00	3·40	2·90	2·08	3·95	1·76	2·65
June	3·60	1·10	2 90	4·90	1·72	1·09	2·63	6·82	3·80	1·73	2·58	1·27	2·92	3·18
July	2·80	2·15	1·43	3·08	1·20	5·31	1·74	3·15	3·96	3·16	4·85	1·30	2·47	2·00
Aug.	2·97	4·45	0·92	2·90	0·93	1·80	2·90	5·67	3·72	0·90	2·05	4·20	1·30	1·97
Sept.	3·15	1·45	2·60	4·42	3·80	2·70	0·50	5·48	1·87	0·70	2·27	3·95	1·80	2·94
Oct.	1·50	6·25	5·83	5·05	2·44	1·47	2·67	3·88	4·23	2·72	5·60	3·35	3·57	1·76
Nov.	3·00	1·70	2·54	1·64	1·70	3·17	0·64	8·95	2·20	1·52	0·45	1·10	1·25	0·83
Dec.	3·30	1·00	3·85	3·63	3·10	2·85	1·65	4·30	1·00	1·48	1·30	2·92	0·84	2·56
	28·92	31·88	30·92	38·04	25·91	31·17	24·81	48·85	32·89	19·93	26·10	32·40	25·04	25·64

Rainfall Observations made at the Pumping Establishment of the Thames and Severn Company at Thames Head. Gauge 350 feet above sea-level.

—	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.	Average of thirty-one years.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Jan.	1·50	2·61	1·40	2·70	2·94	1·78	2·41	3·75	2·72	3·44	4·15	2·70	1·90	5·27	4·12	3·27	5·45	2·92
Feb.	1·54	2·02	2·74	0·46	0·55	1·60	2·17	3·41	2·05	1·39	3·00	2·09	1·17	3·07	1·83	2·25	1·78	1·81
Mar.	2·57	2·46	2·35	4·80	1·08	3·00	1·11	1·11	2·14	2·40	1·18	1·58	1·24	2·25	3·39	1·03	1·00	1·88
Apr.	2·61	1·52	0·76	2·47	1·13	1·06	1·09	2·20	2·55	1·93	1·14	0·57	3·12	2·51	0·65	1·81	2·09	2·05
May	1·41	3·69	1·16	3·78	1·06	1·06	1·86	0·72	2·82	1·39	3·99	1·51	1·89	2·31	2·42	0·81	2·41	2·21
June	3·37	6·13	2·22	2·70	3·54	1·42	0·97	3·21	1·33	0·40	1·48	0·72	3·47	3·25	1·95	1·09	3 09	2·63
July	1·40	1·61	3·77	1·90	0·44	0·94	4·90	2·67	3·71	0·43	0·53	1·18	3·93	5·22	3·01	1·00	5·94	2·61
Aug.	2·56	3·99	0 52	1·76	2·95	1·20	3·93	3·60	2·34	3·96	1·48	2·49	2·66	2·11	2·39	2·74	0·99	2·52
Sept.	3·05	3·08	2·73	3·39	2·96	2 81	..	5·81	1·43	2·95	4·26	1·04	6·33	1·25	1·97	4·40	2·73	2·83
Oct.	2·72	1·89	1·47	3·96	3·57	2·03	5·24	2·37	1·99	2·50	3·21	4·31	1·81	4·11	2·10	4·35	7·44	3·40
Nov.	2·39	2·77	4·26	0·69	2·19	2·16	3·15	1·59	0·98	1·73	2·61	2·00	0·85	4·93	2·38	2·84	4·98	2·36
Dec.	2·74	3·05	1·75	1·65	1·39	2·91	1·56	2·71	2·11	5·57	4·05	1·98	2·30	4·16	0·91	3·06	0·90	2·49
	27·86	34·82	25·13	30·26	23·80	21·97	28·39	33·15	26·17	28·09	31·08	22·20	30·67	40·44	27·12	28·65	38·80	29·71

the tributaries of the Thames and the Thames itself; but since the observations to which he referred it had been ascertained that all the water lost in the higher part of the river came back again through the faults in the strata, and through the gravel bed underlying Cirencester. It was unfortunate that Mr. Symons had not alluded to the possibility of removing existing obstructions from the Thames, which was most favourably situated for the obviation of floods, having a small fall; but it had been altogether neglected. The flow was of a most spasmodic character, and nothing had been done to render it uniform. At Harts Weir there was a narrow channel, only 16 feet wide, through which the river had to pass, and at Radcot there was the old bridge, one arch for the navigation not 16 feet wide, and a side bridge with four 9-feet openings that were of no use whatever until the river was flooded, so that the remedy was not applied until the evil was created. The proper way to treat the Thames was to canalise it from Oxford upwards, and to use it, as heretofore, as a means of central communication throughout the country. Its long, splendid reaches would then be utilised for the purpose of storing and rendering uniform the flow of the river; the water would be delivered by means of suitable sluices, weirs, and drainage channels, which could be simultaneously constructed; and thus the evil originating in the upper part of the Thames and extending to its outfall would be removed. Nothing of the kind had been attempted since the new Board of Conservancy was created in 1866. The Board was established for that purpose, and funds were given for the improvement of the river, but nothing had been done there, though the evil admitted of an easy cure. Putting reservoirs in the valley of the Thames was, in his opinion, out of the question. The whole of the inferior oolite overlying the lias was itself a reservoir, which gave out the winter water stored in the rocks. The variation of the water in the wells was known, and was considerable; and there was no necessity whatever for creating artificial store reservoirs.

Mr. Rogers Field agreed with Mr. Dines in thinking that Mr. Greaves had been the first to give any reliable results on the question of evaporation from water. The information possessed on the subject in England was meagre and contradictory. The quantities given in Symons's "British Rainfall of 1869," at thirteen different stations, varied from 10 inches to 48 inches, in regular gradation. English engineers had generally assumed 30 inches as the amount, and Mr. Bateman, Vice-President Inst. C.E., in his evidence before the Royal Commissioners on Water Supply, had

adopted that quantity. More attention had been paid to the subject in France, but there also the differences were enormous. The evaporation at Paris was taken by engineers generally to be from 51 inches to 59 inches; but along the Canal de Bourgogne it was said to be from 22 inches to 25 inches. Some years ago a Paper appeared in the "Annales des Ponts et Chaussées"[1] on that point; and it was suggested that either the figures with regard to the Canal de Bourgogne must be wrong, or there was an extraordinary slip of country in which the evaporation was less than half the amount elsewhere. It was further suggested that engineers should, in constructing canals, look out for districts equally fortunate in regard to evaporation. The discussion had been carried on, and eventually the nature of the gauges was inquired into, when it was found that the gauges giving a large amount of evaporation were small vessels, often of metal; while the gauges that gave the small amounts were brick tanks many feet square. Numerous observations had been made in different parts of France by means of brick tanks, and they all gave from 18 inches to 25 inches as the result. The difference in the gauges employed to measure the evaporation was really the key to the whole question. Some years ago he read a Paper on the subject, in conjunction with Mr. Symons, before the British Association,[2] and he had since been engaged on a series of experiments for the Royal Society. He employed a tank, 6 feet square, sunk in the ground, as his datum, and round this placed a number of small gauges of different patterns, similar to those generally used. He found that the small metal vessels gave abnormally high results in consequence of the water in them becoming unduly heated. The conclusion he came to was, that it was impossible to tell the amount of evaporation by small vessels, and that tanks of considerable size were required for the purpose. In fact his observations on tanks agreed very nearly with those of Mr. Greaves. With regard to the depth of water below the rim, that was of vital importance in small vessels, but not to the same extent in the case of a large tank. He had found a considerable amount of condensation on a water surface. He had a self-recording apparatus, showing what was going on every hour, and the conclusions obtained would be presented in a report to the Royal Society.

As regarded the amount of percolation through soil, he had prepared a table showing the results of various observers, and

---

[1] *Vide* 2e série, tome xx., p. 383.

[2] *Vide* Report of the Thirty-ninth Meeting (1869). Part ii., p. 25.

Percolation.

		Dalton.[1]	Evans.[2]	Lawes and Gilbert.[3]	Greaves.[4]	Dickinson.[5]	Evans.[6]	Bailey Denton.[7]	Greaves.[8]
—		Soil.	Soil.	Rather heavy Loam.	Soil.	Gravel, Sand, and Soil.	Chalk.	Chalk, Gravel, and Clay.	Sand.
		3 years.	7 years.	5 years.	14 years.	18 years.	7 years.	1 year.	14 years.
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Winter. October to March.	Rain	**14·2**	**11·9**	**13·4**	**13·6**	**13·8**	**11·9**	**7·8**	**13·6**
	Percolation . . .	5·8	4·6	7·7	7·2	8·6	6·9	3·3	12·4
	Loss	8·4	7·3	5·7	6·4	5·2	5·0	4·5	1·2
Summer. April to September.	Rain	**19·4**	**14·6**	**14·5**	**12·1**	**12·8**	**14·6**	**11·5**	**12·1**
	Percolation . . .	2·6	1·2	2·6	2·5	0·5	3·0	0·8	9·1
	Loss	16·8	13·4	11·9	9·6	12·3	11·6	10·7	3·0
Entire year.	Rain	**33·6**	**26·5**	**27·9**	**25·7**	**26·6**	**26·5**	**19·3**	**25·7**
	Percolation . . .	8·4	5·8	10·3	9·7	9·1	9·9	4·1	21·5
	Loss	25·2	20·7	17·6	16·0	17·5	16·6	15 2	4·2

References to observations:—

1 *Vide* Manchester Philosophical Transactions, First Series, v., p. 360.
2 *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 224.
3 *Vide ante*, p. 59.
4 Tables in Appendix to Mr. Greaves's Paper. *Vide ante*, p. 34 *et seq.*
5 *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 224.
6 *Ibid.*, vol. xx., p. 224.
7 *Ibid.*, vol. xxi., Appendix, p. 82. Outlet No. 9.
8 *Vide ante*, p. 34 *et seq.*

comparing them with those of Mr. Greaves. The summer months and the winter months had been taken separately, as suggested by Mr. Evans. The first horizontal line of figures gave the rainfall, the second line the percolation, and the third line the loss or difference between the rainfall and the percolation, all expressed in inches. This method of treating the matter supplied, he thought, a better insight into the question than treating the percolation as a percentage of the rainfall. The observations were classified according to the nature of the material experimented on—the first four being on more or less retentive, and the last four on more or less porous soils.

It would be seen that the loss by Dalton's gauge was larger than the others—a circumstance to be chiefly accounted for by the construction of the gauge, which had no artificial bottom, but simply a pipe inserted. The other gauges had artificial bottoms, and a pipe below, giving perfect drainage. With regard to the observations of Mr. Dickinson and Mr. Evans, new gauges had been put up in 1853, and the amount of percolation was much less after that date. It was not clear what the difference of filling was, but he thought there could be no question that the gauges in the first eighteen years were filled with a much looser material than those of the last seven years.[1] Messrs. Lawes and Gilbert had adopted the only right mode, that of taking some of the ground in its natural state of consolidation, then underpinning and building round it. Mr. Bailey Denton's experiments were made by gauging the flow from land drains in a field 18 acres in extent. These observations did not extend through the entire year, and therefore the percolation for the summer months was to a certain extent estimated. The amount, however, during the months omitted was so exceedingly small that the error, if any, was of no importance. With regard to the experiments on the more porous material, gravel, chalk, &c., there was a remarkable agreement among them, with the exception of Mr. Greaves's sand gauge. The amount of percolation differed considerably, but in the amount of loss there was a close agreement. It would be seen, however, that the loss indicated by Mr. Greaves was much less than the others. He could not believe that his sand gauge really represented what took place in nature. He had had considerable experience in land drainage, and had gauged the discharge from drains in different kinds of subsoil, and he could not think that there was anything like that amount of percolation taking place in the natural soil. He did not mean to throw any doubt on Mr. Greaves's observations,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., pp. 82, 85, 86.

which he had every reason to believe were strictly accurate, but he thought they could not be taken as a criterion of the amount of water to be obtained by percolation through a sandy soil in its natural condition.

Mr. Payne gave some particulars of the rainfall and the floods in the district of the South Staffordshire Mines Drainage Bill, the works of which were being carried out under Mr. E. B. Marten, Assoc. Inst. C.E. The district, which was in the neighbourhood of Birmingham, was divided by a range of hills into two equal parts, each having an area of 23 square miles. It formed part of the backbone of England, the eastern portion draining by the Tame into the Trent, and the western by the Stour into the Severn. The whole neighbourhood was undermined in every direction, so that as soon as the water got out of its natural beds it ran into the mines and occasioned great damage. The twenty years before 1872 were dry years, and it came to be thought that floods such as occurred before would not occur again; in consequence of which the streams had been much neglected; but in 1872 there was an unusual rainfall (43 inches), causing a flood and much damage. A bill was then brought in to improve the watercourses. The Act was obtained in 1873; the works were commenced in 1874, and were in full progress in 1875. Many people in the neighbourhood complained of the magnitude of the operations; in some cases not only was a large bed made for the stream itself, but extra flood banks were built; and it had been said that Suez Canals were being made to carry rivulets; but the event proved they were not too large. Last year the severe floods filled the stream beds, and the water rose halfway up the flood banks, fully confirming Mr. Hawksley's calculations. Before the works were commenced rain gauges, under the advice of Mr. Symons, had been put up all over the district, though not so fully as he recommended. Six stations were chosen, and the most remarkable rainfalls and floods in the river in 1875 were annexed, together with the corresponding discharge of the river Stour. The usual flow of the river was about 50 cubic feet per second.

	Rainfall.	Flow of Stour.
	Inch.	Cubic feet per second.
July 14th	1·31	600
„ 15th	·40	
„ 20th	1·33	420
September 3rd	·50	351
October 18th	·49	..
„ 19th	1·15	375
„ 20th	·55	468
„ 21st	..	682

The discharge of the Stour on the 21st of October was more than thirteen times the ordinary flow of the river. Here, however, damage had not so much arisen from the overflowing of the river as from the water detained over the whole district in swags and broken stream-courses, and from finding its way into the mines. The fall of rain on the 20th of July at Wolverhampton had been 2·79 inches, of which 1·45 inch fell in forty-five minutes. At other stations it did not exceed 1·83 inch and 1·33 inch. In October 3·69 inches of rain fell in five days upon saturated ground; and had not the works of the Tame been far advanced, incalculable damage would have been done in the thick coal mines about Wednesbury; and as the works were not complete, large tracts of mines were still flooded from this rain. In this district it took three days for the rain to run off after a storm; but when the works were completed it was expected the rain would run off more quickly. So far as they extended, the works had proved effectual in protecting large tracts of mining ground; but where they were incomplete great damage had been done last year.

Mr. TOPLEY said the bearing of agricultural drainage upon floods was a point that appeared to be quite unsettled in the minds of agricultural engineers. Agriculturists, he believed, were unanimous in thinking that ordinary agricultural drainage tended largely to increase the floods of rivers, while some engineers thought it produced an opposite effect. He exhibited a map of the river Coquet, in Northumberland, which rose in the Cheviots and ran to the sea north of the Tyne. The watershed of the river included cultivated land; high moorlands covered with sandstone soil, with heather and peat; uncultivated moorlands on porphyry, where the soil was shallow, and where there was very little heather and not much peat. It was a common observation that the rain now came from porphyry soils through brooks much as it did thirty or forty years ago, while the brooks flowing from the sandstone and from cultivated land came down much more rapidly after rain than they did formerly. That the change was due to trenching the surface, in the case of the sandstone and peaty soils, there could be no doubt. The water flowed out from the peat with great rapidity, and as the result was the same on cultivated land and on the sandstone hills, it was reasonable to suppose that it was produced by the same cause. A great deal had been said about the importance of making store reservoirs for flood waters; and it was desirable that engineers should pay some attention to the peat bogs lying so thickly over the north-eastern moorlands of England. There was an enormous tract of high land

thickly covered with peat, and it was these peat bogs that supplied the rivers draining to the east; they were being trenched with small profit to the owners, but with great loss to the inhabitants of the lowlands farther east. The peat bogs acted as large sponges, or as compensating reservoirs, but they were being yearly destroyed. Hereafter there might be discussions as to making compensation reservoirs in the district, whereas they existed there at the present time, and should be preserved. With regard to the heights to which floods rose, he believed that 20 or 30 feet was an exceptional height in England, and 30 feet was the maximum in Scotland. It was probably not generally known that the Tagus in time of flood rose 100 feet above the ordinary level of the river. This was about 1 mile above the famous Roman bridge of Alcantara. The bridge was partly destroyed during the Peninsular War, and was repaired in 1859. It was a wonderful work, admirably restored; and it was almost impossible to believe that one part was nearly two thousand years old, while the other part had only been completed fifteen years. The greatest known flood came just up to the springing of the arch. On the occasion of a flood in January 1856, the total rise was 101 feet above the ordinary level of the river; it rose 46 feet in twenty-four hours. The greatest rise on record was 114 feet, bringing it just within the limit of safety of the old bridge. It seemed improbable that, during the long years it had existed, there could have been any flood much greater than that, for if there had been the bridge could hardly have stood it.

Mr. Symons, in reply, said in using the expression "miserable mills," he was not referring to Mr. Evans's mill, or mills of that class, but rather to the little mills by which a man could not get a living unless the mill was attached to a small farm.

He believed that in many cases the level of the weirs was fixed higher than it otherwise would be, in order that the mills might have the same amount of water as formerly: such weirs ought to be lowered. He was not before aware of the extent to which the river Thames was throttled in various parts, and he had therefore spoken only in general terms without alluding specially to the bridges. His impression was, that many weirs were kept at their present height to secure an adequate amount of water for navigation, and he could not see why they should not be lowered; if they were, the capacity of the river would be increased, the discharge of water from the land on both sides would be facilitated, and the scour of the river would be augmented, while the depth necessary for floating the barges might thereby be rendered nearly as great as at the present time. Dr. Clark's method of softening water

had sometimes been described as a profitable speculation, the product paying all expenses. If so, why had it not been more generally adopted? He was not aware that it was anywhere in use on a large scale. The impression of Mr. Rawlinson that there were not now the extremes of former years was what astronomers would call a matter of personal equation. The statement that the rainfall oscillated like a pendulum he wholly denied. Such a regular oscillation would be a great boon, enabling the occurrence of wet seasons to be anticipated and provided for. Mr. Rawlinson spoke against averages, but without them how could the extremes to which he had alluded be computed? He had also referred to the immense amount of damage produced by the flood in the Calder, but he did not follow it up by saying whether anything should be done. The object of such discussions was to obtain practical results, and he was sorry that so little had been said on the practical part of the subject. The data given by Mr. Clutterbuck would, he hoped, be preserved *in extenso.* There was no reason why such records should not be kept all over the country, except that people would not give themselves the trouble. With reference to Mr. Merrifield's suggestion as to the supply of two sorts of water, he was afraid that it was impracticable. Would servants always use the right sort? With regard to the filter that was mentioned, it was not of the kind he should recommend for the purification of water from organic matter. As to the floods in the valley of the Nene, he could only say that he had in his possession photographs of Northampton showing the water above the axle-trees of the carts, which was certainly not a satisfactory state of things. The lower part of Northampton had been flooded for a considerable time, and a great amount of illness was the result.

Mr. Greaves observed, in reply upon the discussion, that averages were the backbone of meteorology, and as necessary as a base line to a section. Something had been said about the diagrams being laid down in the manner of ordinates and abscissæ. He deprecated the use of such a mode of describing diagrams which were really nothing more than a pictorial mode of showing progression. He had since put up a second sand gauge and it accorded very nearly with the first. It should be remembered that there was nothing to obstruct the water, that gauge being like a colander. His object was to show the utmost amount of water that would go through sand of a known fineness. The sand employed was that ordinarily laid upon filter-beds—sand that would go through a screen consisting of thirty-two or thirty-three No. 10 wires in 6 inches. As to the discordance between

the opinion of different engineers on the effects of drainage, it seemed to him that the question entirely depended upon whether, in draining, the porosity of the upper soil was increased or diminished. The porosity of the soil had an extraordinary effect in retaining the water in its upper parts. He had sometimes said that if soft door-mats were put on the top of the gauge but a trifling quantity would go through. Anything that retained water near the upper surface had the effect of putting it so much more under the action of capillarity, and then the percolation ceased. That was the condition of the soil in summer, and the water ceased to run through. Perhaps if he were to make the gauge again, and could find a convenient place, he might make it deeper, but it would be rather troublesome to do so. The gauge itself must be above the receiver and the receiver above other outside water, and it was not easy to find a place with the requisite conditions. Slate had been found to be a good material for gauge boxes. The sides of the tank should not be less than 1 inch, and the bottom $1\frac{1}{4}$ inch thick. The bottom should be high enough to hold a lead pipe well flanged, and there should be copper bolts that would not rust. The floating gauge (of which a model was exhibited) might be thinner—at least the inner part, for which a thickness of $\frac{3}{4}$ inch would be sufficient. If too thin the gauge would be burst by frost. Boards were placed under it, so as to give sufficient flotation and keep it near the middle of the tank. With regard to the period of the year at which the tables should close, he agreed with all that had been said on that point, but it was better that the principal register should correspond with the ordinary annual notation. The tables might be looked at in many different ways, and each observer could make the necessary arrangements for himself. He had no great belief in cycles, but the results of the percolation gauge showed that short-water times had occurred nearly every five years. The dry periods, however, and the wet periods did not harmonise. If there was any recurrence of wet periods at all it was at intervals of seven years. The years of minimum percolation were those when the rivers had been lowest. The object of the Paper was to direct attention to the small quantity of water available. The rainfall, as sometimes given, was in reality as 1 yard to 1 inch of available water. Some persons had said that more evaporation ought to be shown by his tables, and, consequently, less percolation. If the percolation was too great the quantity of water available would be still less. Observers had usually endeavoured to measure the evaporation, and by deduction to arrive at the percolation. That had generally been

found to make the evaporation appear more than the rainfall; and of course any series of observations carried out on that basis must soon be discarded. A single gauge 1 yard square could hardly be said to resemble the whole 500 square miles, the watershed of the Lee, but there was a general resemblance in the character of the soil. The most extraordinary instruments had been used for measuring the evaporation, including tin pans which could not possibly be correct. The last he had seen was from Vienna, an elegant little thing, with a micrometer screw. The water to be put into it was not more than 1 pennyweight! It was useless as a gauge of evaporation. The longer his experience, the more he felt the necessity of having the gauge for measuring evaporation to float in water. He did not think that the idea of setting apart a piece of a reservoir in which to experiment was so good as that of making a box (the larger the better) float in the water to be tested. His own gauges, however, were set up originally to ascertain the maximum of percolation, not the amount of evaporation. If reduced to one gauge, he should prefer the land-percolation gauge. A knowledge of river delivery was the next most desirable thing to attain; and if a good series of figures were forthcoming, which could be put in comparison with his probable percolated quantity, they would be very acceptable. A series of gaugings of the river Lee had been commenced in 1850; but the time had not yet arrived for making them public. He did not think at the commencement of the inquiry that a waste-pipe would be a good thing; and he therefore filled his gauge to within 2 inches of the top, and he intended the percolation to be compulsory. The gauge itself was ordinary soil, shut in and underdrained, subject to the action of insects. The surface was thrown up by frost every winter and softened; this added to its porosity and to the capillary action. He had thought of digging out a cube of ground, hoisting it, and dipping it into the gauge; but he did not consider that the sides of the gauge could be joined to the block of ground so as to preclude the chance of an interstice round the edges; he therefore adopted the method described. He wished Mr. Symons's Paper had given the proportion between the flood water of a river, the ordinary discharge of a river, and the rainfall. As he had not done so, he would hazard the following:—That the ordinary discharge of a river was supplied by one-sixth of the rainfall, and of a river when in flood by one-tenth; and that the sum of those two was nearly the same as the result given by the ground-percolation gauge.

Mr. Stephenson, President, said he had been for upwards of seven-

teen years engaged in the construction of some of the heaviest works on the Fen rivers. He would only mention that the plan adopted by him was to carry the low water of the sea as far as possible inland; and for that, in one case, the company for which he was concerned received £60,000 from one upland drainage company alone.

Professor D. T. Ansted remarked, through the Secretary, that it must be evident to engineers that much more depended on the relation of the drainage area to the capacity of the channel to carry off flood waters than on the absolute rainfall. By improving the effective channel, and by regulating the discharge, when either of these was possible, much might be done to reduce the mischief that would otherwise be effected by occasional floods. When neither could be done—when the natural features were such that the obstructions by narrow throats to large, wide-spreading valleys could not be removed—floods were inevitable. When, also, artificial obstacles held back flood waters the result was the same. But mills, and mill-dams, and occasional reservoirs, if properly constructed, acted rather as flood regulators. Mr. Symons had introduced the question of the contamination of water, and something had been said on the same subject by Professor Merrifield. Though not properly arising out of the two communications under discussion, he wished to express his conviction, derived from some experience, that in the great majority of cases, in all parts of the world, polluted waters became potable after a comparatively short time by some natural process of cleansing. That there were exceptional cases he would not deny, but he would suggest that in most cases the supply of water to rivers took place much more by ground springs than was generally estimated, and that the mixture of water thus introduced might have an important influence in purifying. He had occasion, some years ago, to estimate the volume of the Derwent between two points where there was no addition by feeders, and where the increment by bottom springs more than doubled the supply in a few miles. That the main supply of water from springs, whether artesian or by deep sinking, was derived directly from the rainfall of some time previous, and to no appreciable extent by underground reservoirs, or by any store of water held in rocks as in sponges, there was, he believed, full proof. He was surprised to find Mr. Homersham still thought it possible to obtain an indefinite supply of water from the chalk, without affecting neighbouring springs and rivers. He was certain, from actual experiments, and from continued observations, that all supply

from the chalk was derived from rain which entered by innumerable fissures, drained to the lowest available surface, and remained there till drawn off by natural springs at a lower level, or pumped to the surface by deep wells. He was equally certain that exhaustive pumping gradually drained a large district below the natural and ordinary level of the water, both above and underground, in that district. Mr. Homersham was right in assuming that a vast body of water existed in the chalk, but he was wrong in believing that any part of this water could be obtained at the surface without an equal quantity being removed from crevices and fissures that communicated with the surface. These remarks applied not only to chalk, but to limestones of all kinds, to sandstones and sand rocks, and even to granite. All rocks (using the term rock in its geological meaning) were more or less fissured, and let down water, and he had seen in Cambridgeshire cracks in the Kimmeridge clay a yard wide and of great length, opening to immense depths, as the result of a drought of a few weeks; and in other countries fissures in clay and loam converted into valleys, open to the sea after several miles' course, produced by the drought and subsequent rain of two seasons. Fissures existed in all rocks, and they were the means by which springs were everywhere fed. Much of the water conveyed by rivers was obtained from the overflowing of springs. Mr. Greaves had assumed that the records he had given of percolation and evaporation were new, and yielded results not hitherto recorded. It was only fair to previous observers that their labours should be acknowledged, and if the works of Mr. Howard were referred to, as recorded in Mr. Beardmore's hydraulic tables,[1] it would be found that all now stated was known, such of it as regarded evaporation, more than half a century ago, and as regarded percolation, as far as the Dalton gauge could record it, a quarter of a century ago. That no better means than the Dalton gauge had been obtained was to be regretted. That contrivance was never of much value as a practical instrument, inasmuch as it referred only to land covered with soil and grass, and took no account of the fissures produced in all such cases in nature, and the large intervals where the rocks were not protected, and to the difference in percolation that must occur according to the nature of the subsoil and rock. No account had been taken in Mr. Greaves's calculations of the deposition of dew. It was long since the effect of evaporation had been recognised, and allowance made for it in those important groups of

[1] *Vide* "Manual of Hydrology," p. 293.

storage reservoirs constructed in various parts of England during the last half-century. But no general law could be stated, and it was certain that the amount varied exceedingly from year to year. It had, of course, no relation to the rainfall, or, rather, what relation it had must necessarily be an inverse ratio. Perhaps no subject in the whole range of physics and physical geography as applied to engineering needed more careful consideration, and more painful investigation, than that of the percolation into and evaporation from rocks and soils; but he begged to submit that the methods of experimenting must take a wider range, and involve a more general consideration of all the associated phenomena than had yet been given, to justify practical conclusions that the engineer could accept.

Mr. T. Fenwick observed, through the Secretary, that to confine a stream between two banks during a flood, which otherwise would have spread over a tract of land on either side, would, in his opinion, tend rather to prevent than to cause a deposit in the channel. A river bed was often seen lifted up by a deposit of gravel where flood banks now line its course; but the embanking was the result, and not the cause, of the altered level. In carrying out works for the improvement of the river Aire in Craven, observations had convinced him that, next to increasing the surface inclination of the river, by the removal of natural and artificial obstructions in its channel, the most efficacious means of reducing the flooding of adjoining lands to a minimum was to increase the sectional area of the river by widening or deepening the channel, and, with the excavated soil, to form flood banks at such a distance from the river-side as circumstances might require or render expedient. Painful experience had, however, satisfied him that improvements of this kind could not be carried out without Government aid and support. "Vested interests" of one kind or another reared their hydra heads; and litigious obstructives, with their imaginary grievances, were sure to crop up, effectually burking private enterprise or patriotism. One experiment of this nature, undertaken for the benefit of a particular district, or for the good of the community, would be sufficient to quench the spirit of the keenest philanthropist.

Mr. E. J. Lloyd, through the Secretary, referred to the Midland area of England, which formed the boundary-land of the watershed areas of the Thames, Avon, Welland, Nene, Trent, and Ouse, and said it was remarkable on how small an area those rivers had tributary streams, and consequently how largely they were affected by a heavy rainfall on a limited area. It was also singular

that all the reservoirs of any considerable capacity within this area had been constructed for canal purposes, and that although as a matter of course they were restricted with regard to level, and as to site, they were all, with the exception of the Napton and Stockton Reservoirs (the former of which was on the blue lias clay and the latter on the white lias rock), situated exactly upon the outcrop of the marlstone overlying the lower lias clay, and consequently on the marlstone drift or on the outcrop of the Northamptonshire sand beds. This proved that the constructors, about the commencement of the century, considered this geological position the only available one for reservoir purposes within the district. The experience gained in the management of the Napton reservoirs led him to affirm that the construction of safe reservoirs, of large area, and having considerable fluctuation in the water-level on the lower lias clay, was practically exceedingly costly and difficult, if not impossible. There were other questions affecting the proposed construction of storage reservoirs and works for the purpose of preventing or diminishing the extent of floods, such as the effect of lately constructed works, as railway bridges and embankments across river valleys, which had apparently been overlooked.

Professor Prestwich observed, through the Secretary, that the large area of impervious strata drained by the Thames and Cherwell must always render them liable to floods of such magnitude, that however useful a moderate amount of storage might be in affording the means of securing an important addition to the water supply in times of drought, Mr. Symons's valuable records amply confirmed the opinion that no practicable extent of storage could be effectual as a remedy in staying their action. Large natural reservoirs, in fact, already existed, compared with which any artificial reservoirs which could be constructed would be insignificant. The Thames along its whole course flowed through alluvial flats of greater or lesser breadth. In the neighbourhood of Oxford, for example, the valley spread out to a width of 1 mile to 1½ mile for a length of 4 miles to 5 miles, or equal to an area of 3,000 acres. Both lower down and higher up the valley there was a succession of such basins, in all of which the alluvial clay was underlaid by a bed of gravel varying from 5 feet to 20 feet in thickness. The gravel rested on impervious Oxford clay, and it was the same all the way to Cricklade; while below Abingdon there was a large area of equally impervious gault, and, below Maidenhead, of London clay. The drainage works in progress at Oxford for the last eighteen months afforded unusual opportunities for noticing the effects of the rainfall on this bed of gravel, for

the main drain had been carried near the side of the valley through the alluvial clay and gravel for a distance of 2 miles below Oxford, and to a depth of about 16 feet. At the bottom of the gravel there was always a sufficient quantity of water to supply the wells to a village of seven hundred inhabitants, standing in the middle of the valley, and to supply the adjoining reservoir for the waterworks of Oxford. In dry weather the water in the wells might stand at 12 feet below the surface, and at one time early last summer the water-level was below the base of the trench in which the main sewer was being laid. As the rain continued, the water gradually rose until the whole depth of the gravel was charged with water. Then, this underground reservoir being full, and the rain continuing, the water rapidly rose to and above the alluvial clay, and floods ensued. He would suggest whether some of these great natural reservoirs might not be utilised by engineering works for a storage of winter water to increase at times the summer delivery of the river; such as by damming back, at the narrowest passages, the water held in the gravel in the larger basins when fully charged, and conducting it to lower levels down the river in periods of drought.

With respect to the effect of mills and locks on the floods, he questioned if they had contributed in any important degree to causing anything more than comparatively small and local results, except in a few cases. The Thames, in all times, had been a river subject to floods. Before the present régime came into operation, floods spread out the great beds of gravel which underlaid the alluvial clay from side to side of the valley, and since then, the alluvial clay which covered the gravel had been the result of floods which, commencing in prehistoric times, were continued through early British occupation, during which the river must have flowed without restrictions, through historical times up to the present day. The root of the evil seemed, therefore, to lie deeper than the secondary causes which were first apparent.

The questions relating to the quality of water were hardly to be discussed by incidental observations. They had been fully treated elsewhere, and the few points brought forward by the Author of the first Paper had received, not long since, a full investigation, of which all the evidence was on record. That sewage contamination was an evil of too common occurrence there could be no doubt, but to base, not the present, but the past history of a water, and to condemn it, on the presence alone of two salts, by the term of "previous sewage contamination," was, he thought, fallacious, as these salts neither proved the nature of the contamination, nor

did their absence prove the water to have been free from previous contamination. A water of known bad origin might be free from them, and water of good origin might contain them. It was of no use, in an inhabited country, seeking an impossible ideal standard. The great object was to get water which, from a knowledge of its origin, was known to have been as little polluted as possible by house or town refuse, and in which ordinary natural agencies had reduced to a minimum, or altogether removed, those results of pollution. Up to a recent period there was hardly a river or a permeable stratum free from these abuses. The rivers were now, happily, in course of having these abuses removed, but it was not so with permeable strata. Immunity could not even be claimed for the chalk. Every house and every village situated on a chalk hill drained into the chalk, and that drainage found its way with the rainfall to feed the deep springs and wells. But, after all, the population in chalk districts was comparatively small, and the great extent of filtration was sufficiently effective for its purification, in the same way that the flow and aeration of rivers effected the same object. Although the necessity was not so apparent, he could not but think that the permeable strata, on which underground water supply depended, needed protection equally with rivers. The observations of Mr. Greaves had an important bearing on the rate and extent to which such underground springs were fed by the rainfall. It would be desirable to see similar experiments made with gauges constructed of such materials as formed other water-bearing strata, such as sandstones, oolites, limestones, gravel, &c., in order to determine the rate of percolation in these several formations; while the observations of Mr. Symons should be supplemented by simultaneous observations on the rainfall and the delivery of the rivers at given points, so as to determine the exact relation between the rainfall which he now so accurately registered and the escape of the flood waters.

Mr. Redman, through the Secretary, directed attention to the figures quoted by the Author of the first Paper, as his estimate of storage required for great floods, viz., 160,000,000,000 gallons, or 714,285,714 tons of water, which enormous quantity was no doubt correct, although it was from three to four times the daily ordinary tidal flow from Teddington to Gravesend. The principal flood of 1875 through the Albert Bridge at Windsor, observed by Professor Unwin of Cooper's Hill College, amounted to 14,102 cubic feet per second, or 33,723,925 tons daily. Mr. Symons's estimate of storage was therefore equal to nearly twenty-one days of that great flood. Now the ordinary Windsor winter discharge was

only 746 cubic feet per second, or 1,798,392 tons daily, *i.e.*, $\frac{1}{17 \cdot 64}$ of the great flood of 1875. The ordinary daily discharge at Twickenham amounted to 3,250,000 tons, or $\frac{1}{10}$ the amount of the great flood. At Kingston the maximum discharge in 1866 amounted to 8,000,000,000 gallons daily, or 35,714,285 tons daily, *i.e.*, 2,000,000 tons in excess of Professor Unwin's gauging—not greater than might be expected, the one being above the tributaries, the Colne, Mole, &c., and the other below. Other Kingston floods had occurred of 6,000,000,000 gallons, equal to 26,765,714 tons daily. Now the ordinary tidal volume above bridge amounted to 14,750,000 tons, and below, to Gravesend, to 92,750,000 tons: or a total of 107,500,000 tons, *i.e.*, 215,000,000 tons daily. And 50 per cent. might be added to this quantity for exceptionally lofty spring tides, making 322,000,000 tons daily. Thus the land flood water, when in its greatest excess, amounted to $\frac{1}{9}$ of the tidal water: and as one-half the land water passed off with the ocean ebb, this proportion was only $\frac{1}{18}$. The recent exceptionally high tides attained the following relative elevations, viz. :—

	Above Trinity Standard.		Above Admiralty Estimate.	
	Feet.	Inches.	Feet.	Inches.
20th March, 1874	4	6	2	3
15th November, 1875	4	9	3	3
13th March, 1875	3	9	2	6

So that the maximum elevation of 39 inches above the estimated range of the day by the hydrographic authorities of the Admiralty was the quantity to be dealt with. Now $\frac{1}{18}$ of this quantity amounted to a depth of 2·16 inches only as representative of the land water influence when at its maximum, and meeting an exceptionally lofty range of tide produced by a westerly gale. The practical inference from these facts was, that whereas up to the present time an elevation of 4 feet had been taken as the standard height for the wharves, it was now evident that a minimum elevation was necessary of at least 5 feet above Trinity standard of high water spring tides for the metropolitan quay surfaces, due mainly to the removal of old London Bridge, the consequent raising of high water, the lowering of low water, and the increased range developed by the modern Thames Embankments.

Mr. John Taylor supplied, through the Secretary, the table on the following page.[1]

[1] A record of the daily volume of water flowing down the river Thames, for the years 1853–73, will be found in the "Sixth Report of the Commissioners appointed in 1868 to inquire into the best means of preventing the Pollution of Rivers." London, 1874, Appendix, p. 474.

VOLUME of WATER FLOWING DOWN the RIVER THAMES OPPOSITE the LAMBETH WATER-WORKS SEETHING WELLS, THAMES DITTON, for the YEARS 1853 to 1875 (inclusive).

The quantities are given in thousands of gallons.

Year.	January.	February.	March.	April.	May.	June.
1853	..	42,941,208	37,616,046	30,914,380	32,512,856	20,081,642
1854	60,737,874	28,098,578	19,629,106	15,512,394	15,293,859	15,376,218
1855	12,813,219	18,799,600	21,920,402	15,439,448	13,810,888	13,565,687
1856	44,130,564	[1] 37,240,780	22,982,916	26,201,542	26,665,952	20,318,401
1857	48,905,756	26,106,676	19,538,616	25,228,218	15,567,245	14,704,458
1858	15,876,342	24,606,444	16,825,819	27,490,447	17,361,893	13,024,509
1859	15,976,154	21,606,810	17,716,720	17,696,976	15,785,204	14,552,238
1860	61,248,016	[1] 36,998,098	28,828,514	21,529,262	17,055,937	42,803,402
1861	57,327,588	38,982,600	36,242,326	22,656,252	18,386,227	17,213,957
1862	26,730,318	24,109,142	57,430,932	64,175,454	45,273,346	26,762,836
1863	46,886,784	22,687,326	17,628,417	16,843,663	14,604,570	15,267,915
1864	17,734,063	[1] 16,884,615	47,893,642	21,940,241	16,732,041	14,912,569
1865	19,555,756	38,358,914	24,497,968	15,393,561	14,353,811	13,657,663
1866	90,654,088	81,572,280	34,030,028	26,728,828	19,145,514	15,854,465
1867	50,206,416	51,238,338	47,018,846	30,553,370	22,857,850	20,264,986
1868	46,682,949	[1] 24,738,804	25,937,794	19,429,357	15,775,098	14,000,629
1869	72,744,228	85,605,290	31,433,328	18,442,302	21,983,953	15,029,880
1870	35,184,878	37,685,084	29,757,694	16,631,144	14,529,482	13,461,835
1871	21,910,205	16,773,192	15,311,781	14,092,586	13,445,076	13,100,551
1872	68,001,884	[1] 42,543,365	28,604,516	29,819,434	23,032,240	18,831,019
1873	90,908,196	40,783,850	51,395,474	24,190,738	18,460,986	18,326,908
1874	22,200,724	21,930,474	25,619,458	19,333,188	17,448,882	16,464,454
1875	57,285,518	38,035,610	33,604,426	22,014,256	18,368,514	17,199,699

Year.	July.	August.	September.	October.	November.	December.	Total of each Year.
1853	29,230,430	20,635,256	21,405,510	47,226,750	29,344,754	29,449,780	[2] 341,358,612
1854	14,989,621	14,161,605	12,322,215	13,017,978	13,893,183	14,095,418	237,128,049
1855	14,473,875	15,272,475	13,128,053	22,982,297	41,861,134	21,893,519	225,960,597
1856	14,794,745	14,445,233	14,277,864	25,338,636	16,986,237	32,886,376	296,269,246
1857	15,290,414	16,290,644	15,259,011	32,226,903	25,485,058	18,330,774	272,933,773
1858	12,696,057	12,438,493	12,023,011	12,997,482	12,573,874	14,458,653	192,373,024
1859	12,660,207	12,456,089	12,590,088	15,354,353	25,219,748	35,539,605	217,154,192
1860	34,539,630	34,991,040	39,488,458	33,424,328	35,989,370	67,998,970	454,895,025
1861	16,978,797	14,461,422	13,846,746	15,734,806	22,896,373	27,163,900	301,890,994
1862	19,131,468	17,132,615	14,532,312	22,613,707	18,229,812	22,041,668	358,163,610
1863	14,232,701	13,197,049	13,762,725	15,822,914	22,023,346	21,400,513	234,357,923
1864	13,345,082	12,816,604	13,318,015	13,620,078	14,384,381	16,141,153	219,722,484
1865	14,461,673	14,365,784	12,462,777	18,171,520	29,050,829	24,670,318	239,000,574
1866	16,088,346	15,484,615	18,425,527	22,892,774	24,288,450	31,489,802	396,654,717
1867	17,472,543	15,584,586	16,340,920	16,476,540	15,436,861	18,271,007	321,722,263
1868	13,637,714	13,783,853	12,706,605	12,311,195	13,982,634	49,135,815	262,122,447
1869	13,218,124	13,374,467	13,599,106	15,115,579	15,072,890	36,695,682	352,314,829
1870	14,027,897	13,793,582	13,574,262	16,550,170	14,204,181	12,054,778	231,454,987
1871	14,559,609	12,969,193	12,624,023	19,725,059	13,524,433	15,791,916	183,827,624
1872	18,743,328	20,168,742	16,930,645	19,731,014	33,003,290	94,715,280	414,124,757
1873	18,841,482	18,228,037	18,080,748	18,988,560	19,664,056	18,141,378	356,010,413
1874	16,321,381	17,274,712	15,976,059	17,827,535	17,687,663	31,937,344	240,021,874
1875	25,868,894	19,173,630	16,549,707	57,063,544	103,274,440	28,457,162	436,895,400

[1] Leap years. [2] For eleven months.

Mr. W. H. Wheeler remarked, through the Secretary, that the rainfall of the eastern part of the Midland district was less than in any other part of England. The cloud which produced such heavy rain in the south-west in July 1875, appeared to have travelled across the country to Lincolnshire at the rate of about 20 miles an hour. Commencing at Plymouth about 3 A.M. on the 14th, the rain reached Boston between 3 and 4 P.M., and gradually expended itself as it travelled northwards. The quantity registered during the time of its continuance, about thirty-six hours, was 1·08 inch. The long period of dry weather, which had lasted nearly four months, broke up at the end of June, nearly 1 inch of rain having fallen on the last four days of that month, and from the 27th of June to the 21st of July 4·79 inches. The total rainfall for July was 3·82 inches, the average for the previous twenty years being 2·29 inches. The heaviest falls in July during the last twenty years had been in 1851, 5·73 inches; in 1855, 4·10 inches; in 1865, 5·29 inches; and in 1866, 4·42 inches. The heavy fall of rain in the middle of July 1875 came with easterly and north-easterly winds; it was not due to sudden and violent thunder showers, but to a steady and continuous downpour spread over twelve days. The effect of this heavy fall was not so serious in the Fens as in other parts of England. Owing to the physical character of the district, and to the absence of mountains or high lands, and also to the absorbent nature of a great part of the soil constituting the watershed of the Witham, consisting principally of oolite and fen land, only a small portion of the rainfall found its way into the river. It was at least a week after violent floods were reported as existing in the West of England before the rainfall made any sensible impression on the rivers. The Witham did not begin to rise until the 17th, and it then only rose a few inches. The river was at its highest on the 22nd, the rise being only 3 feet above the level of the water previous to the rain. The Witham drained 1,063 square miles of land, about one-third of which was fen land, the height of the country at its source varying from 200 feet to 300 feet above the sea. The Black Sluice drain, which gathered the water from about 200 square miles, one-half of which was fen, only rose 1 foot above its previous level. The Glen, which received the water from the lands bordering on the Black Sluice district, owing to the greater elevation of its watershed, and its imperfect outfall, rose to a great height, and filled the river in some parts bank-full, or within about 8 inches of the flood of April 1872, the highest known. The reservoir of the Boston Waterworks at Miningsby, which received the

drainage of about 3 square miles, and was upwards of 30 acres in extent, rose 10 inches from the 18th to the 25th, the brook which fed it, though dry in June, running a fair stream. The rainfall for July at Miningsby was 4·33 inches, the average consumption of water being about 300,000 gallons per day. The engines employed to pump the water off the low-lying fen lands had all to be set to work, and although no flooding occurred, it was many years since so strong a stream ran down the Haven.

When nearly every other part of England was flooded by the heavy fall of rain during October, no practical inconvenience was felt in this district, the extensive works of embanking and draining having proved effectual in this trying emergency. The fall of rain at Boston from the 9th to the 23rd of October was 3·34 inches, the highest point to which the water rose in the Witham above the sill of the Grand Sluice having been 11 feet 6 inches on the 24th, the ordinary height of a winter flood. The total fall for the month was 3·50 inches as against an average of 2·30 inches. The rainfall in November was 4·90 inches, being 3·16 inches above the average, and the greatest fall for that month on record, the nearest being in 1852, when 4·32 inches fell. The aggregate depth of rain during September, October, and November was 10·64 inches, a larger quantity than in any year since 1852, when 11·05 inches fell during the same period. Rain falling previous to September had generally little effect on the water supply or floods in the Witham; but on this occasion, owing to the heavy falls in July and October, the ground was completely saturated, and one of the heaviest floods known for many years occurred. On the 13th 0·93 inch of rain fell, in addition to 2·17 inches since the beginning of the month. On the evening of the 14th a high spring tide stopped the flow of the fresh water down the Witham, during which the land water rose above the sill of the Grand Sluice to 15 feet 6 inches, the highest point ever recorded, the next highest having been 14 feet 6 inches in November 1852, and 14 feet 7 inches in January 1857. Although this had been one of the heaviest and most wide-spread floods in the district since the improvement of the drainage, yet compared with other places the damage had been trifling, and with the exception of some of the lowest grounds not yet drained by steam power, and in one small district where the bank broke, very little land had been sufficiently inundated to suffer serious damage; showing what might be accomplished by a proper regulation of the water channels, by improving the outfalls, and by embanking the main streams. In

no part of England had so much money been spent in drainage and river engineering as in the Fens, and the past season had demonstrated the good effect derived from the outlay.

Mr. E. L. WILLIAMS remarked, through the Secretary, that Worcester had happily escaped the full force of the deluge of rain in July, which had fallen with such destructive violence upon the valleys of the Stratford Avon and the Wye. On the 14th of that month the fall of rain at Worcester was but 2·20 inches; and the height of the Severn flood had been in some measure due to the backing up of the water by the great influx from its tributaries below Worcester. The highest winter floods in the Severn, near Worcester, were about 22 feet above low-water level. Previous to the erection of the weirs at Tewkesbury and Gloucester the floods occasionally rose to 24 feet above the same level, covering the Diglis lock walls to a depth of 1 foot 6 inches above the copings. Since the erection of the weirs at Gloucester in 1870 the floods, notwithstanding the heavy rainfall during October and November last, had never been upon the Diglis lock walls. He mentioned this as an illustration of the fact that properly-constructed weirs facilitated the passage of flood waters.

March 7 and 14, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

The discussion upon the Papers, No. 1,464, "On the Floods in England and Wales during 1875, and on Water Economy," by Mr. G. J. SYMONS, and No. 1,409, "On Evaporation and on Percolation," by Mr. C. GREAVES, occupied both these evenings.

The following Candidates were balloted for and duly elected on the 7th of March:—JOHN BRANDT, WILLIAM DUFF BRUCE, WILLIAM ROBERTSON COPLAND, WILLIAM DENNY, ALEXANDER DUNCANSON, WILLIAM GALWEY, HENRY GREENBANK, CORNELIUS LUNDIE, GEORGE WELLS OWEN, and JOSEPH MILLER WILSON, as Members; JAMES GREY ADAMSON, WILLIAM BULL, JAMES LAWRENCE CHAPMAN, HENRY WILLIAM CHURCHWARD, THOMAS COLE, ALFRED COLSON, THOMAS COLSON, CHARLES WILLIAM DEMPSEY, MAX AM ENDE, WILLIAM HAY FEA, ALBERT BROWN GHEWY, Col. EDWARD CHARLES ACHESON GORDON, R.E., ROBERT WOOD EVERETT GREEN, WILLIAM AUGUSTUS GORMAN, KILLINGWORTH WILLIAM HEDGES, Stud. Inst. C.E., WILLIAM I'ANSON,

Alexander Jervis, Edwin Kenworthy, Hamilton Lindsay-Bucknall, James George May, Henry Miller, Jun., Alexander William Moore, Stud. Inst. C.E., James Watson Murray, William Peel, Henry Kerr Rutherford, Edward Taylor Simpson, Henry Goulton Sketchley, Stud. Inst. C.E., William Scarlett Trehearne, John Francis Weedon, and Joseph Henry Wild, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 7, of the Bye-Laws, had transferred Robert Rowan Purdon Hickson and Richard Harris Hill from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—Clement Henry Allen, Demetrius Frederick Charlton, Charles Clegg, George Coulton, Howel Fenoulhet, Horace Arthur Fisher, James Staats Forbes, Jun., Arthur Werner Itter, Edward Fountaine Jacob, William Gyllick Newton, Francis Orange, James Orange, Charles de Graves Sells, William Shears, Jun., Herbert Blomfield Smith, Theodore Charles Troubridge Walrond, and John Waddington, Jun.

March 21, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

No. 1,468.—"Hydraulic Canal Lift at Anderton, on the River Weaver." By SIDENGHAM DUER, B.Sc., Assoc. Inst. C.E.

THE river Weaver, running east and west through the centre of Cheshire, forms an important, though not generally known, system of inland navigation, which of late years has increased greatly in utility, owing principally to the development of the salt trade in that part of the county. It is navigable for a distance of 21 miles for steam barges of 200 tons burden, from a little above Winsford to Western Point, near Runcorn, where it flows into the Mersey. The river has, during the last one hundred and fifty years, been improved from time to time by the Trustees by whom it has been managed. But as trade has increased so much lately, it devolved upon Mr. Edward Leader Williams, Jun., M. Inst. C.E., late Engineer to the Weaver Trust, and now Engineer to the Bridgewater Navigation Company, to carry out many important works for its development, and to initiate others, some of which have already been successfully accomplished, as well as others designed by Mr. John Watt Sandeman, M. Inst. C.E., the present Engineer to the Weaver Trustees.

Among the facilities for traffic which Mr. Williams considered necessary was a ready means of communication, at Anderton, between the Trent and Mersey Canal and the river Weaver, so as to save the expense and loss of time involved in the transhipment of salt, pottery, and other goods. The first expedient which suggested itself for achieving this object was, that the barges should be raised and lowered between the canal and the river by a chain of locks; but this idea had to be abandoned, on account of the great space which would have been required by the locks, of the great delay in passing boats through them, and of the scarcity of water in the canal. Mr. Williams then thought that the barges might be lifted and lowered by hydraulic presses, without taking any water from the canal, and he consulted Mr. Edwin Clark, M. Inst. C.E., upon the subject. The canal, which for some miles runs parallel and close to the river, is on the top of a bank, while

the river is below. The difference between the levels of the wat in the canal and in the river is 50 feet 4 inches. The proble therefore, to be solved consisted in devising an expeditious mea of raising and lowering laden barges through this height, and a which at the same time should both occupy as little land and u as little water as possible. It was thought advisable that t barges should be lifted while floating in a trough of water, obviate all danger of straining, in the event of their cargo shifting. This necessitated lifting the weight of the water in t trough as well as the barges, and was found to require a larg steam-engine. It was then proposed to make the lift double, or t have two equal troughs which, being by some means connected should counterbalance each other, like a pair of scales, when only one-half of the engine power would be required. It was further improved by the idea of taking a little water into the upper trough from the upper level, so as to make it heavier than the lower one, and that in its descent it should do nearly all the work of lifting the other trough. After the various designs had been considered, the works, of which the following is a description, were decided upon, and the arrangement of the details was intrusted to the Author by Mr. Edwin Clark, under his own supervision and that of the Engineer to the Weaver Trustees.

General Description of the Works.

In what is called the Anderton basin, there is an island in the river Weaver which was fixed upon as the best site for the lift. It was decided that the water of the canal should be carried in an aqueduct, at its normal level, across the river between the bank and the island, and that the boats should be lifted and lowered between the end of this aqueduct and a cutting from the main river into the island.

The works constructed at Anderton consist of a basin opening into the Trent and Mersey Canal; a wrought-iron aqueduct to lead the water of the canal from the basin across an arm of the river to the end of the lift pit; a double hydraulic lift, situated on the island, capable of lifting from the level of the water in the river to that in the aqueduct or canal, and a channel cut through the island from the lift pit to the main bed of the river, for barges to pass to and from the lift and the river. The sides and closed end of the lift pit are of red sandstone from the neighbourhood. The sides of the basin at the canal end of the aqueduct are brickwork, faced with red sandstone. This basin is much wider than

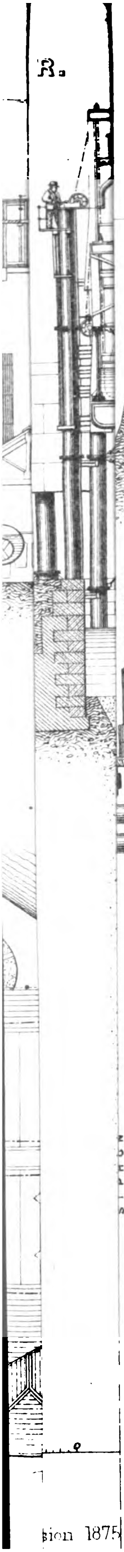


Fig: 5.

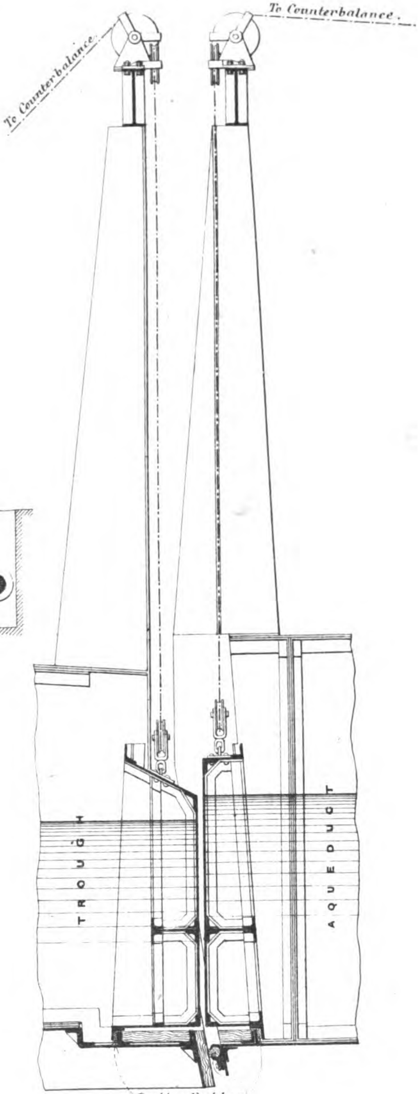
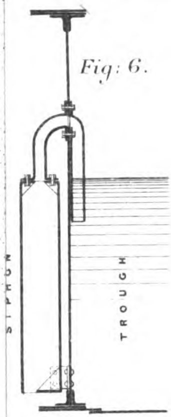


Fig: 6.



THOS KELL LITH 40 KING ST COV

the aqueduct, so that barges can there wait their turns to be lowered into the river, or to pass into the canal, as may be required, without hindrance to the traffic of the canal.

Plate 2, Fig. 1, shows a side elevation, and Fig. 2 a plan of the works. Figs. 3 and 4 are cross sections of the lift and aqueduct. Fig. 5 gives some details of the arrangement of the gates for the aqueduct and troughs, as well as the method of making the joints between the aqueduct and troughs. Fig. 6 is a section of one of the siphons for insuring the proper depth of water in the troughs; and Fig. 7 gives some details of the main valves for working the apparatus, and of the method of controlling them.

Aqueduct.

The aqueduct is of wrought iron, 162 feet 6 inches in length, and 34 feet 4 inches in width, in three spans of 30 feet, 75 feet, and 57 feet 6 inches. A central web divides it into two channels, each 17 feet 2 inches wide. This central web and the sides of the aqueduct are 8 feet 6 inches deep, and form continuous girders, which carry the aqueduct, and the water, 5 feet 3 inches deep, contained within it. The total weight of the aqueduct and the water is 1,050 tons, or about 6½ tons per lineal foot. The webs of the aqueduct girders are strengthened by wrought-iron gussets, to resist the outward pressure of the water, and they are also strengthened by wrought-iron overhead arches, which tie them together where the outward pressure and the compression on the top flanges are at a maximum. The bottom skin plates are supported by transverse floor girders, 1 foot 9 inches deep and 5 feet apart, which transmit the pressure on the bottom to the centre and side girders. There is also a small floor girder, 9 inches deep, connecting the larger floor girders in the centre of each half of the aqueduct, and extending from end to end. The aqueduct rests on a cast-iron bed plate, on the masonry of the basin at the canal end, and at all other points it is supported on cast-iron columns.

To insure a water-tight connection between the aqueduct and the basin, the cast-iron bed plate on which it rests is built into the masonry of the basin. The top of this bed plate was covered with red-lead, and the bottom skin of the aqueduct was bolted to it. The inner edge of the bed plate was chamfered off, and the space between this chamfer and the skin of the aqueduct was caulked with wooden wedges. The sides were made water-tight with the

masonry, by running in Portland cement at the backs of wooden fenders which protect the ends of the aqueduct girders.

The columns A B bear on Portland-cement concrete, contained in cast-iron cylinders, which rest upon a foundation of masonry supported on piles. The columns C, and all other columns round the lift pit, are carried down to below the bottom of the pit, and stand on foundations of brickwork and concrete. Each end of the aqueduct is fitted with wrought-iron lifting gates for controlling the ingress and egress of barges. As the aqueduct is divided into two separate channels, it follows that two such gates are required at each end. The weight of each gate is about 27 cwt. This is principally counterbalanced by weights D working over pulleys. The gates are lifted perpendicularly by a small crab and pulleys attached to cast-iron frames, which also serve as guides while the gates are being lifted or lowered. There is one crab to each gate, and one man can lift the gate 7 feet 6 inches clear of the water in about a minute and a half. This is quite high enough to allow the largest barges to pass under. The gates have a strip of indiarubber fastened to the back of the flange, round their sides and bottom, and the internal pressure of the water forces it against a corresponding angle-iron flange fixed to the aqueduct, so that a water-tight joint is made.

Lift.

The lift is double, and the barges are raised or lowered while floating in a box or trough, full of water, so arranged that one trough containing barges, in coming down to the river, assists in lifting barges in the other trough up to the canal. Each trough is 75 feet long, and 15 feet 6 inches wide, and is long enough to hold the largest barges that can be used on the canal, and wide enough to hold one of the largest or two of the small ordinary barges. The small barges each carry from 30 to 40 tons, the larger barges from 80 to 100 tons, of goods. The troughs are constructed entirely of wrought iron, their sides forming girders 9 feet 6 inches deep in the centre, and 7 feet 6 inches deep at the ends. These girders support the entire weight of the trough, with its load of barges and a depth of water of 5 feet. The sides of the trough are stiffened to resist the outward pressure of the water, by external gussets like those of the aqueduct, but there are no overhead arches. The pressure on the bottom is transmitted to the side girders by transverse floor girders 1 foot 9 inches deep, and by longitudinal floor girders 9 inches deep.

At each end of a trough there is a lifting gate, similar in construction and mode of operation to those described for the aqueduct. At the sides there are a number of cast-iron siphons for securing whatever depth of water the circumstances of lifting may require. Each of the troughs is attached to the head of a cast-iron ram by a central wrought-iron socket 3 feet 6 inches deep, bored to fit the turned head of the ram. From this socket wrought-iron cantilevers radiate to the side girders of the trough to transmit the weight from the side girders to the ram. Each trough is thus entirely supported and moved up and down by one central vertical ram 3 feet in diameter.

This ram passes through a stuffing box in the bottom of the lift pit, and through the tunnel into the press. The wrought-iron tunnel under the lift pit, 4 feet 4 inches in diameter, is to afford easy access to the valve box E, and to the glands of the presses and stuffing boxes, for the adjustment of the packing, and for lubricating the rams. The weight of each trough, with the water and barges contained in it, is 240 tons, which is equal to a pressure of about $4\frac{3}{4}$ cwt. per square inch of the area of the ram. The rams and presses are of cast iron, in three lengths, joined together by flanges and bolts. The flanges of the rams were covered with red-lead before being bolted together. The flanges of the presses, besides red-lead, have a ring of lead wire between them, which, being squeezed flat by the pressure of the bolts, makes a water-tight joint up to the required pressure. The presses, pipes, and all other parts of the apparatus were tested to a pressure of 6 cwt. per square inch before being used. The presses are below the bottom of the lift pit, within cast-iron cylinders 5 feet 6 inches in diameter, sunk to the required depth by the pneumatic process. They fit into cast-iron bed-plates, laid on two layers of wood, each 4 inches thick, resting on the Portland-cement concrete at the bottom of the cylinders. These bed plates are fixed in their places laterally by Portland-cement concrete between them and the inside of the cylinders. Besides resting on the bottom bed plates, the presses can also rest on the tops of the cylinders containing them, which have large external flanges, so as to give a great area of foundation. At the corners of each of the troughs there are cast-iron guide blocks, which work against guides on the columns round the lift pit, so as to keep the troughs steady while they are in motion. The guides and guide blocks are accurately planed and carefully fitted.

The guide columns are supported, below the bottom of the lift

pit, on foundations of brickwork and concrete. They are filled with ballast, and built into the masonry round the lift pit to increase their weight and stability. At the aqueduct end of the lift pit they are braced to the columns supporting the aqueduct, and are tied to the aqueduct itself. At the river end they are braced together, and to a central column 10 feet 6 inches distant from the centre guide column, so as to form a large triangular buttress of great strength. This is tied at the top to the guide columns at the aqueduct end of the lift pit by the lattice girders, which also carry a platform; and halfway between the ground and this lattice girder this buttress is again tied to the same columns by other small lattice girders, placed horizontally to resist wind, and slung from the platform girders so as not to sag. These girders are thus kept straight, and form efficient tie rods.

The distance between the guide columns is sufficient to allow a trough, when disconnected from the top of the ram, to be floated between them out of the lift pit; and as wooden gates can be fitted to close the river end of the lift pit, the water can be pumped out, and all parts of the apparatus easily got at for repairs. A platform round the aqueduct and lift pit, at the height of the water in the aqueduct, for the manipulation of the gates, for moving barges in and out, &c., allows all parts of the apparatus to be easily seen from it. There is an accumulator, to assist in working the lift, having a ram 1 foot 9 inches in diameter, with a stroke of 13 feet 6 inches; it has a capacity equal to that of one of the main rams for a stroke of 4 feet 6 inches. The two main presses are connected by a pipe 5 inches in diameter (Fig. 7), fitted with an equilibrium valve, E, for opening or closing communication between them.

There is also a pipe, 4 inches in diameter, for each of the presses, passing from the accumulator through continually open passages in the valve box E. These pipes are opened or closed separately, as required, to the accumulator by valves, F, situated under the end of the aqueduct. Thus the accumulator can be opened to either or both of the presses as may be wished. From a T piece on each of the 4-inch pipes, between the valves for controlling them and the presses, a waste pipe, 2 inches in diameter, goes up to the valve house, and there passes into a valve box by which the water in the press with which it is connected can be run to waste into the aqueduct. A branch on each of these waste pipes contains a small safety valve, which is lifted whenever an ascending trough may be going too high, and the water running to waste prevents danger. These pipes and valves, excepting those for carrying the water from a

steam-engine to the accumulator, are all that are required to work the lift; and are controlled, by means of shafting and gearing, by one man in the valve house, who turns one of five wheels according as he wishes to open or close the valve between the two presses, to open or close either of the presses to the accumulator, or to let the water in either of the presses run to waste. The relative position of the wheels in the valve house is the same as that of the valves themselves; so that the man stands, as it were, in the centre of a model of the lift. This man works the lift in accordance with signals from others whose business it is to bring the barges into and out of the lift. The valve house is on the top of the aqueduct, and commands a good view of the whole apparatus.

Mode of Working.

To understand the principle of action of the lift, let it be granted, in the first place, that for a given depth of water in a trough, the weight on the ram supporting it is constant, whether there are barges floating in the trough or not. Again, let it be granted that, if the weight of the two troughs and their inclosed loads be the same, and the communication between the two presses open so that the water can pass freely from one press to the other, the apparatus will be in equilibrium when the two troughs are at the same level. On the other hand if one trough be heavier than the other, the heavier will fall nearer to the lower level and force the lighter one up as much nearer to the level of the canal. Suppose now that all the valves are closed, that one trough is at the aqueduct level, while the other is down in the lift pit, that the upper trough contains water 5 feet deep with or without barges floating in it, and that the lower one contains water 4 feet 6 inches deep with or without barges floating in it. If the valve E on the 5-inch pipe is now opened, so as to allow a free communication between the two presses, the upper trough will descend and cause the lower or lighter one to ascend, until, by becoming partially immersed in the water in the lift pit, it loses part of its gravitation, and has lifted the other trough to within about 4 feet 6 inches of the top of the lift.

The communication between the two presses is now closed, the water still remaining in the press supporting the descending trough is allowed to run to waste into the aqueduct, and the trough consequently descends into the water of the lift pit, and the barges contained in it have now been lowered from the level

of the canal to the level of the river. The gate at the river end of the trough can accordingly be raised, and the inclosed barges floated out into the river and be replaced by others waiting to be lifted. Meanwhile the man in the valve house opens the connection between the accumulator and the press of the ascending trough, and the accumulator forces this trough up to 6 inches below the top of the lift. It does not force it up all the way, because it is necessary that the water should be 5 feet deep instead of 4 feet 6 inches when the trough is descending, and the simplest way of increasing the depth of water is by running it in from the aqueduct. Before the barges can be transferred from this trough to the aqueduct, or even water can be allowed to flow between them, a water-tight joint must be made between the end of the trough and the end of the aqueduct. For this purpose the ends of the trough and aqueduct are bevelled, as shown in Fig. 5, and a facing of wood is fitted on to the end of the trough and correctly adjusted to the bevel of the face of the aqueduct. A round piece of indiarubber, 3 inches in diameter, is fixed on the face of the aqueduct by attachments of malleable cast iron, and as an ascending trough is lifted by the pressure of the accumulator the indiarubber is squeezed between the two bevelled surfaces, and makes a water-tight joint. After this joint is made, a valve is opened in the aqueduct gate, to allow water to pass between it and the gate of the trough, and the aqueduct gate is lifted as soon as the water-level is the same on both sides. The trough gate is now pushed just clear of its indiarubber face by the pressure of the extra 6 inches head of water in the aqueduct, and can therefore be lifted directly after the aqueduct gate, when the water flows rapidly into the trough from the aqueduct to make the two levels identical, and the depth of water in the trough becomes 5 feet instead of 4 feet 6 inches. Barges can now of course be transferred between the trough and the aqueduct as required.

When the gates have been again closed, and the trough is allowed to descend, the water between the two gates falls through a hose pipe into the lift pit below. It will be observed from the shape of the gates that the space between them is made as small as possible to prevent waste of water.

When a trough descends into the lift pit it is always immersed to a depth of fully 5 feet, to get barges in and out easily, and when the river is swollen the immersion may be still greater. It being, however, absolutely necessary for the working of the lift that the depth of water while the trough is being lifted should not be more

than 4 feet 6 inches, the extra water in the trough is drawn off by the siphons already alluded to. While a trough is descending into the lift pit, as each of the siphons dips into the water, the air within the siphon is driven out through its shorter leg inside the trough, which becomes nearly filled with water; and consequently, when the trough is again lifted, the siphon, having a partial vacuum within it, draws water out of the inside of the trough down to the bottom of its leg, or until air is admitted into the outer leg by the water falling below the bottom of a small adjustable pipe connecting it with the water in the inside of the trough. Siphons for letting the water out of the troughs are preferred to valves because they are automatic, whereas if valves were used each of them would have to be opened while the trough was at the bottom of the lift to let water out, and closed again when at the top of the lift to prevent the loss of the 6 inches depth of water which comes into the trough from the aqueduct. As there are twelve siphons to each trough, this would seriously delay the operations of a machine required to work so quickly as the one being described. It was stipulated that the lift was to be performed in three minutes; it has been done in about two minutes and a half, and by increasing the quantity of water taken from the canal it could be effected more speedily even than this.

Besides being worked as a double lift, each trough can be lifted separately by the engine and accumulator; but this is a comparatively slow operation, and occupies about half an hour. With ordinary care, no accident can happen to the apparatus from frost, as all the exposed pipes are protected with felt, and at night it can be entirely emptied of water by opening two little valves placed on the lowest exposed parts.

It will be understood from this description that the motive power employed for working this lift is of two kinds. The first part, and in fact quite eleven-twelfths of the entire lift, is performed by taking a layer of water 6 inches deep over the surface of the upper trough, that is to say, a weight of 15 tons from the canal, and the remaining one-twelfth is performed by a small steam-engine continually pumping water into an accumulator.

The obvious advantages in having the lift double, so that it can be worked as described, are the saving of engine power and time. For, if eight minutes elapse between the commencement of each lift, the double lift requires an engine of 10 HP., supposing 20 per cent. of the power to be lost through friction, &c., to take up two barges and bring down two others simultaneously. A single lift could, however, only take two barges

up or bring two down in eight minutes, so that sixteen minutes would in this case elapse between the commencement of each lift. And even at this speed, and to do only half the work of a double lift, an engine of nearly 65 HP. would be required, and a very large accumulator. In the double lift, each press, with its insistent trough, is in turn an accumulator to the other, and does its own useful work of lifting and lowering.

Among the advantages possessed by this apparatus over a flight of locks is the unimportant quantity of water used; only 6 inches of water over the surface of the trough are required to work the lift, whereas in a flight of locks one lockful will always be taken from the upper level as a boat passes down, and one or several lockfuls will be taken by an ascending boat, according as the locks are full or empty. In a chain of six locks, with a total fall of 51 feet, the depth of water taken from the upper level will therefore be 51 feet if the traffic is equal in each direction, instead of the 6 inches required for a lift. There is also an immense saving of time; eight minutes are sufficient for the whole operation of transferring two barges from the river to the canal, and two others at the same time from the canal to the river. The Author is informed that in a flight of locks at Runcorn, where the difference of level is the same as at Anderton, it takes from an hour and a quarter to an hour and a half for a barge to go through. The staff required consists only of one man in the valve house, one engine-driver, and three labourers for attending to the troughs and taking boats into and out of the lift. The total working expenses, including stores and a clerk to check the tonnage, are under £10 per week.

The ironwork and machinery were supplied and erected by Messrs. Emmerson, Murgatroyd, and Co. (Limited), of Stockport and Liverpool; and the foundations, masonry, and sinking of the cylinders were carried out by the Trustees of the River Weaver, from the designs and under the superintendence of Mr. Sandeman. Since the apparatus was opened by the Trustees, in the beginning of July 1875, no alterations or additions have been required; and great satisfaction is expressed with the way in which the lift works, and the ease with which it is manipulated.

The Author is persuaded that this method of raising barges from one level to another may always be adopted with advantage, instead of flights of locks, where considerable differences of level have to be overcome. The first cost would be less, in addition to the advantages in the saving of water and of time; and he is convinced, from his experience at Anderton, that lifts on this prin-

ciple may be constructed, not only for raising and lowering barges, but for large vessels; and if canals should be constructed to divert the goods traffic from railways, where it at present causes great inconvenience, and sometimes serious accidents, such lifts must then be frequently employed. It has been explained that at Anderton, where saving of water is of great consequence, a very small amount of engine power suffices. It will be readily understood that where water can be more easily spared a steam-engine might be entirely dispensed with, and a turbine or some other application of water power employed instead.

In conclusion, the Author has to express his best thanks to Mr. Sandeman for kind co-operation and for valuable suggestions connected with the details of the work. He has also to testify to the thoroughly efficient way in which the Contractors did their work, and to the good quality of the materials employed.

The communication is accompanied by a series of drawings, from which Plate 2 has been compiled.

[Mr. E. Leader Williams

Mr. E. LEADER WILLIAMS, Jun., said the Author had so elaborately traced the details of the lift that little room for explanation was left. The river Weaver was a navigation of great importance, though little known out of the county of Cheshire, where, however, it was highly valued, because until lately it had produced a sum of between £15,000 and £20,000 per annum in reduction of the county rates. Up to the time of the construction of this lift it was, so to speak, merely a blind alley, leading from the Mersey at Weston Point up to the salt district of Northwich. The production of salt in that district was about 1,250,000 tons per annum, of which 1,000,000 tons were conveyed on the Weaver for shipment to Liverpool. When Engineer to the Weaver Trustees, he thought it was a pity that a navigation on which so much money had been spent—more money for its length, 21 miles, than on any other navigation in England—should depend solely on salt traffic, and the lift was designed with a view to join it with the canals at Anderton. The Trent and Mersey canal passed close to the river on the top of the cliff, and the question to be solved was, how best to construct the lift, as there was no room for an incline. There was nothing at all new in a canal lift. In the first volume of the Proceedings of the Institution there was a Paper descriptive of perpendicular lifts for passing boats on canals, as erected on the Great Western Canal,[1] but those only dealt with boats of 8 or 10 tons, while on the Weaver the craft were of 100 tons, and the height to be raised was 50 feet 4 inches. A strong lift was therefore required; but it appeared worth trying, and the Weaver Trustees placed the matter in his hands. He first designed a system of counterbalance weights with water, which undoubtedly was cumbersome. Fortunately at that time he was induced to visit the hydraulic lift graving dock at the Victoria Docks,[2] and on seeing the ease with which ships of 2,000 tons were there handled, he perceived that that was a proper mode in which to deal with the smaller craft on the Weaver, although the height was so great in the latter case. He put himself in communication with Mr. Edwin Clark, and with Mr. Duer's assistance the scheme was evolved. At first he was in favour of two presses, for it appeared to him that a long caisson or trough of 75 feet was rather too much to trust to one press; but on going into the question a difficulty arose about getting the two presses to work equally. That was a serious matter, because it was clear that if with a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1838), p. 26. Also, Transactions Inst. C.E., vol. ii., pp. 185–191 (with three plates).

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., pp. 292–309.

trough full of water one end was lifted faster than the other, more weight would be thrown on the other press. The proposal to have two presses was therefore given up, and one 3-feet ram was adopted. It had been a most successful work, and he had seen two boats taken up and two boats lowered in two and a half minutes. The work had been admirably carried out; it was perfectly water-tight and it did the contractors great credit. It was evident that if there had been any "scamping" such a work would have been a failure. He had expected to encounter some difficulty in the junction of the trough with the aqueduct, but by the adoption of the bevel form, and by the pressure against the rubber-joint, a water-tight joint was obtained, so that not a drop of water escaped. In that respect it had an advantage over the Monkland incline,[1] with a trough on wheels on which the load was supposed to float, but the boats were generally dry at the bottom of the tank when it got to the bottom of the incline. On the Weaver, however, the boat floated the whole of the time; and to his surprise the canal boatmen with their wives and donkeys took to it most comfortably, and although stairs had been provided, they were not used. Many eminent engineers, including Telford, Cubitt, and Sir John Hawkshaw, had been engaged in improving the river Weaver, and now 200-ton steamers worked from Winsford to Liverpool. Twenty years ago vessels of 100 tons only could be accommodated. What had been done was a good instance of how much could be accomplished by capital judiciously expended in assisting navigation. Great praise was due not only to Mr. Duer for the care which he had given to the details of the work, but also to Mr Sandeman, who had carried out the foundations in a most efficient manner.

Mr. EDWIN CLARK remarked that in this case the novelty consisted in lifting a piece of the canal itself, and not simply a vessel on a pontoon. Practically, the canal was continued over the river until it became vertical above the spot to which the barge was lowered, and a piece of the canal descended with the barge in it; similarly that same piece rose again. One of the difficulties experienced in docks was, that the vessels were said to be strained and damaged in many ways, but that had been got over in the present case by lifting and lowering a piece of the canal itself, so that it was impossible for the barge owners, however rotten the barges might be, to say that they had been damaged. The lifting of so large a pontoon with a single press was a problem which had involved a good deal of thought. It was a large press, with

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiii., pp. 205–209.

a long stroke, and it was a question how far, with so heavy an overhanging weight, reliance could with safety be placed on a bracket of that kind. But inasmuch as the load was immovable, the water being quiescent, it appeared to be a case in which there was no danger in putting on the top of the single press a weight which, with any varying load, would have involved danger. He was convinced, from the experience on the Weaver, that the limit to which a single press might be applied had not been attained. He did not think there would be any difficulty in raising ships of 700 or 800 tons, and in fact a question of that kind was being considered in respect to the navigation of the Volga, where vessels of large dimensions had to be raised in the canals. The hydraulic lift was capable of application in a way which, perhaps, at first sight might not be imagined. Many rivers, like the Volga, were subject to great rises and falls, and in such cases considerable difficulty was incurred by the engineer when he wished to communicate between the river and the canals. The Volga was sometimes, for instance, 1 mile wide, and at other times 3 miles wide, overflowing muddy banks on each side, and it was no uncommon thing for its level to vary 30, 40, or 50 feet in three months. Under such circumstances it became a difficult problem how canals should be connected with such a river. Now, the system followed on the Weaver was peculiarly applicable to such a case; for it was only required to run the canals over to the river itself, to be independent of the level of the river, whether it rose 10, or 30, or 50 feet. All that was necessary was that a maximum lift should be provided to meet the greatest difference between the level of the water in the river and in the canals. He thought the principle was capable of great extension and application. The rising and flowing of tides in harbours had been a difficulty for engineers to contend with, but in the plan described in the Paper they were totally independent of the level to which the river might rise or fall, having always the same facility for lowering or raising any load. In that respect he thought the system would hereafter be found of considerable utility.

Mr. J. W. SANDEMAN observed, through the Secretary, that from an intimate acquaintance with the construction and working of this ingenious canal lift, he was pleased to be able to confirm what the Author had stated as to its complete practical success. Although the number of barges at present transferred by its means was comparatively small, yet it was increasing, and there was reason to look forward to its more extended use, when sufficient time had elapsed to enable a traffic more commensurate with its

capabilities to be developed. In 1872, when he succeeded Mr. E. Leader Williams, Jun., as Engineer to the Weaver Navigation Trustees, he found the contract for the ironwork and machinery of this canal lift had been let. During the progress of the work, in discussing the details with Mr. Duer, he was much impressed with the readiness and confidence with which expedients were devised for overcoming the difficulties that necessarily presented themselves in such a novel work. He could not speak too highly of the ease with which the lift was worked, and of the forethought displayed to provide against all contingencies. He should also make mention of the watertightness of the various joints, with which there had not been the slightest trouble. The saving of time and of water effected by this lift had been referred to, as compared with a chain of locks. The saving in time would, in many situations, be an object of great importance, particularly upon a navigation where many locks existed in close proximity; also in cases where the advantages of more rapid transit, by steam towing, must be to a certain extent neutralised by the slow process of locking. The mode of towing barges in trains could also be readily provided for in a lift, by an extension of the lifting troughs or caissons, and by increasing the number of rams. The saving in water was also an important feature, as, assuming the up and down traffic to be equal in tonnage, the loss of water would only be a depth of 6 inches, as compared with the depth of the deepest lock in any series of locks; because, in comparing the lift with a chain of locks, it must be assumed that, by means of intermediate basins in the latter, barges could be passed up or down continuously.

In carrying out the foundations of the canal lift, and the masonry of the basins and approaches, the design and execution of which devolved upon him, the following features might be interesting. The foundations for the press cylinders, which contained the lifting rams, were provided by sinking cast-iron cylinders of 5 feet 6 inches in diameter to a depth of about 70 feet. The ground in the interior was excavated by hand, and the water excluded by compressed air, which at one time reached 26 lbs. per square inch above atmospheric pressure. The pneumatic process had to be resorted to, in consequence of the great infiltration of water from the river, through the strata of sand and gravel, which extended to a depth of upwards of 50 feet; but below this, the hard stratified marl, which overlaid all the rock salt in this district, was reached, and this formed an excellent foundation for the press cylinders. The piling for the support of the retaining

wall for the upper basin had to be of a substantial character, in consequence of a portion of the superstructure having to be built upon the face of a bank composed of sand and clay. The bottom of the upper basin was puddled clay, about 1 yard in thickness, and below the level of this clay apertures were left through the masonry of the retaining walls, so as to prevent any accumulation of water behind by infiltration from above; and although slight leakages showed themselves at first, through these apertures, they soon ceased, and therefore proved that there was no further risk of water permeating through the clay bottom of the basin.

Sir William Armstrong said it generally happened that the best Papers were the least productive of argument, for the simple reason that nothing in them was capable of being disputed, and the present Paper was a case in point. It was a good feature in the scheme that the vessels were maintained in a state of flotation during the operations. By that means unequal strains were avoided, which would necessarily be involved in lifting the vessels by direct attachments. Another good feature was that chains were entirely dispensed with, the lift being performed by the direct action of the press. He quite agreed that, by an extension of the same system, weights might be lifted far exceeding any that had hitherto been contemplated. So impressed had his firm been at Elswick with the desirability of using direct lift with presses, where the weights to be lifted were very great, that the system had been applied to shears and cranes, and a crane was being constructed to lift 160 tons by a press suspended at the end of the jib. A ram was not used, as in the present case, but the alternative of a piston. The press was suspended on gimbals at the end of a long jib; and although the lift was 50 feet, no difficulty was anticipated in raising the load directly, and at the same time in giving to this mode of suspension all the flexibility of chains. The same arrangement was also being applied to shears for lifting 120 or 130 tons. Both those machines were rendered necessary by the enormous weight that guns had now reached. Guns were attaining such a weight that they could hardly be moved about at all, and chains were so treacherous, and involved so many probabilities of accident, that his firm had been obliged to dismiss the idea of using them.

Mr. A. Giles said some years ago he designed and erected a pair of shears for the purpose of lifting 100 tons. He proved them up to that weight, and they had been since constantly used, but he quite indorsed what Sir William Armstrong had said about the risk of trusting to chains. There had never been an accident with the shears, but he could quite see the force of the remarks about

the advisability of using appliances like those which, under the practical management and design of Mr. Edwin Clark, had proved so successful. But the expense of putting up a pair of shears even to lift 100 tons was limited compared with the cost of the apparatus described in the Paper; and although he fully admitted the admirable way in which the matter had been brought forward, neither the cost of the work, nor the cost per ton of raising or lowering, nor the amount of work that could be done in a day, had been given. If the Author would supply these details he thought the members would be much benefited.

Mr. E. Leader Williams, Jun., said, unfortunately the work had been let when the price of iron was at a maximum, and considering the large proportion of iron employed, that fact made a difference of almost one-third in the cost. His original estimate was something like £16,000, but he was bound to say the cost of the lift had been a great deal more than that. He did not remain there long enough to be able to give an opinion as to the exact working; but, from his knowledge of the place, he considered the scheme was much cheaper than working a chain of locks. In the latter case there must have been five or six locks. Brindley, with great skill, put his chain of locks at Runcorn, and from there he ran up the Trent and Mersey to Middlewich, and also up the Bridgewater Canal to Manchester and the North at one dead level. Now any work proposing to take water from these canals to a river which had already more water than was wanted at once raised a storm of opposition. The Bridgewater Trustees of course thought this to be a serious matter. They had a right to think so, because the lift was to take the traffic of the Trent and Mersey and the Bridgewater Canal, and allow it to go down the Weaver and join the Mersey at another point. He felt the difficulty of devising some method by which water might not be wasted, and the scheme was carried in Parliament notwithstanding opposition. He was in a peculiar position with regard to the matter, because he was now Engineer to the Bridgewater Navigation Company, and he was bound to say it was not his original plan to use 6 inches of water each time, but to pump it back again to the canal. As it happened, however, the descending weight of goods was so much greater than the ascending weight that there was no practical loss of water. The cost of working was moderate. There was one man at the engine house and one man up in the office above actuating the working valves. If there had been a chain of locks the cost of working and of maintenance would have been greater. He quite felt, however, that the cost of the work should have been stated in the Paper, though it

had been so large for the reason which he had mentioned, namely, that iron was at the time excessively dear. He thought if the work had to be done again the cost might be much reduced. Although one of the lifts acted as an accumulator to the other, yet it was not always possible to secure that a barge should be going in at one end at the precise moment that another was going in at the other, and he thought there was not that practical advantage in having two rams and two lifts that he had previously anticipated. If the work had to be done again, he thought one-third of the cost could be saved by only using one ram, and by putting the pressure on to a large accumulator, and he believed that, in actual practice, as much work might be done in the day. Certainly one ram and one lift would suffice for the work that was likely to be required on the Weaver for the next thirty years.

Captain GALTON said, there were several large canals in the centre of England where water was much required, and he wished to ask if the system described was applicable to those canals which already possessed locks. The Author had said that if a boat descended a series of locks 50 feet it would require a depth of water of 50 feet to take that boat down, but in reality in descending the locks the boat would only require about 8 feet 6 inches for each lock. On the canal with which he was particularly acquainted, the Birmingham Canal, which had probably the largest traffic in England, it was arranged that a boat should always go up at the same time that a boat came down. By these means it was generally contrived, where water was scarce, that no more than one lockful of water should be lost each way. If a comparison had to be made between the system described and a chain of locks, that point should be taken into consideration in the question of cost. Of course last year there was an abundance of water, but sometimes water was so excessively scarce, that it was necessary to have it pumped back, and he wished to know what was the cost of the present scheme as compared with the cost of pumping back the water.

Sir JOHN HAWKSHAW, Past-President, thought this lift was a proper application of the system in this particular case. If the Author was able to state the cost, that should be compared with the cost of a series of locks to get up the same height. If there were 10-feet locks, five would be required on the Weaver, and he was afraid that the cost of these could not be given; and the same observation would apply to that which Captain Galton seemed desirous of ascertaining, namely, whether a system of this sort would be universally applicable to canals. He thought it would not. There might be cases, where there was abund-

ance of water, where it would be better to go on according to the old method of making locks, but there were other cases where it might be desirable to apply the particular mode of lifting a boat from one level to another described in the Paper. When the matter was under consideration, there were only two points which had presented any difficulty. One was the mode of making a joint; whether it should be according to the plan which had been adopted by making the faces bevelled, or by putting a small press at the other end, so as to press the trough against the face. The other question was that of poising the somewhat long trough upon one single press.

Mr. Bramwell observed that the works on the Weaver had been compared to the incline on the Monkland Canal.[1] Two or three years ago he had occasion to look into the working of that incline. There were certain points of similarity, and also of difference, in the two cases, which perhaps it would be as well for him to allude to. The incline on the Monkland Canal was worked by means of a travelling caisson upon wheels, and that caisson certainly was quite competent to keep the barge which it brought up afloat the whole time, if it were so desired; but the reason given for not allowing the barge to float was, that an oscillation was set up, and then the barge was liable to beat against the doors of the caisson and do harm. As much water, therefore, was deliberately let out as it was thought necessary, to allow the barge to settle upon the bottom of the pontoon, while leaving water enough to support the barge, and thus to prevent its being strained by the cargo. The caisson was wound up by a chain, and there were ratchets alongside, and palls, which would go into gear at any time in the event of the chains breaking. The joint at the top was made with indiarubber, and there was an hydraulic press to give the final push to the caisson to close this joint water-tight. The pontoon having come up with as much water in it as would just fail to float the barge, there was a difference of level between the water in the caisson and that in the canal, and thus it happened that when (on the indiarubber joint being closed) the doors at the end of the canal and at front of the caisson were opened, the water coming out of the canal into the caisson had sufficient velocity to drive the barge outward by the mere regurgitation of the current. Alongside the Monkland incline there was a staircase of locks, which presented, by their cost, complexity, and obstructiveness, a strong contrast to the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiii., pp. 205–209.

travelling caisson system. He could state, from being in possession of the whole of the particulars, that the saving in point of time, as compared with the locks, was undoubtedly considerable, as was also the saving in first cost. It appeared to him that for a great height of lift the ordinary locks—a necessity when mechanical science was not far advanced—should never now be resorted to; if such a proposition as that were agreed to, the question was reduced to one between an incline and such a lift as had been described. He thought the incline had one advantage—that if anything gave way, the ratchets and palls provided a check; while if anything gave way in this lift, the whole affair would come down with a hideous crash. He could not help thinking that the press cylinders should have been of wrought iron. It was true the pressure per square inch was not great; but after all, cast iron was a treacherous material, and he should have liked to see the external cylinders made of wrought iron; or if cast iron were retained, it should be hooped. As a measure of precaution it might be well to have two other rams, one at each end, not to aid in raising the load, but simply to draw water into their cylinders as they rose, which water would on their descent flow out through small apertures, sufficiently large to admit of the free exit of the water when the load descended at a proper pace, but so small as to check the outflow demanded by a too rapid descent, and in this way serious accident might be prevented.

Mr. John Corry observed that there were some points of detail in which he thought improvement could be effected. He considered that the making of the joint by the bevelled facing was defective in principle, inasmuch as the pressure of the water in the aqueduct tended to separate the tank. By a simple method of interlocking one vessel coming up behind the other, the pressure could have been directed so as to make the joint more perfect, and in a large work he thought some such arrangement would be absolutely requisite. It would also prevent the necessity for any of the external support at the end, because the pressure would be thrown on the aqueduct.

Mr. J. W. Sandeman furnished, through the Secretary, a statement showing that the prime cost of the ironwork and machinery, including the royalty, of the hydraulic canal lift at Anderton was £29,463, while that of the foundations of the lift, masonry of basins, approaches, &c., was £18,965, making a total of £48,428. About September 1872, when the contract for the ironwork, &c., was let, the price of iron had reached the highest point ever

known in this country. In this particular lift the aqueduct, which contained the greatest portion of the wrought iron comprised in the work, was longer than would be necessary under ordinary circumstances, in consequence of its having to span a branch of the river before reaching the site for the lifting troughs or caissons.

With the lift in full operation the working expenses per week amounted to about £15, to which should be added £93, or 10 per cent. on the prime cost, being 5 per cent. for interest and 5 per cent. for depreciation, making a total of £108 per week.

In estimating the full capabilities of the lift for traffic, it had been calculated that an equal number of laden barges and of light barges would be transferred continuously. Taking all the circumstances into consideration, it would not be justifiable to assume that a greater traffic would be conducted by its means, for, although in many instances the same barges which might pass through it in one direction laden would also return laden, yet it would not be possible to maintain a continuous succession of barges passing through the lift. The lift was capable of transferring sixteen barges per hour, eight up and eight down, and, proceeding upon the basis assumed, this would give four hundred and eighty light and four hundred and eighty laden barges transferred per week; the laden barges at present averaged about 25 tons burden each, or 12,000 tons of goods transferred per week, which, divided into the average working cost per week, gave 2·16*d.* per ton. The parliamentary tolls were :—

	s.	*d.*
Per ton for all goods	0	1
For each laden barge	1	0
For each light barge	2	6

Tolls for one week's traffic would therefore be :—

	£.
12,000 tons at 1*d*..	50
480 laden barges at 1*s*.	24
480 light barges at 2*s*. 6*d*.	60
	134

If, therefore, the lift were in full operation, the tolls would more than cover the working expenses, interest on first cost, and charge for renewal. The lift was likely to prove much more remunerative by attracting trade to the navigation which it did not possess before; it had already done so to some extent, and this trade paid toll for the navigation independently of the tolls charged for the use of the lift.

Mr. Duer, in reply, said he had not given any details as to the

outlay upon the work because he thought they would be misleading; and though Mr. Sandeman had answered the questions as to first cost and cost of lifting per ton, he did not think it was fair to the system to take those figures as guides in estimating the expense of such a lift. The subsidiary works connected with the lift at Anderton were of an extensive character, and part of them were not properly chargeable to the lift. The contract for the ironwork, which formed so large an item, was let when the price of such work was higher than it had ever been. The foundations were much more substantial than would generally be considered necessary. The neighbourhood of Northwich being liable to serious subsidences, as the brine was pumped from beneath the surface of the ground, it was essential to provide, as far as possible, against any contingency of that kind occurring with the lift. He thought also that less extensive basins and approaches might have sufficed, and that the banks of the lower basin might have been merely sloped and pitched. Further, if the peculiarities of the site had not rendered an aqueduct indispensable, then the expense would have been greatly decreased. Taking all these facts into consideration, he did not hesitate to say, that such a lift, with the subsidiary works, could generally be constructed for about one-half the outlay at Anderton, and consequently that the cost of lifting per ton might be less than $1\frac{1}{2}d.$, instead of $2 \cdot 16d.$, as calculated by Mr. Sandeman.

It was originally proposed to have four presses, one at each corner; but with four presses it would have been difficult to keep the trough horizontal, in case a leakage occurred in one of them, and the weight being only 240 tons, he thought that was not too much for one press 3 feet in diameter. If it was necessary to construct a large lift on this principle for vessels of 1,000 tons, or upwards, a few presses could be grouped together at or near to the centre, and if all were connected they would practically form one press, without any of the dangers that might accrue if they were separated. With regard to the quantity of water that was taken by boats passing up and down through a chain of locks, if two boats with equal displacement, traversing a system of inland navigation, had to pass each other at a chain of locks having a total fall of say 50 feet, they could not do so without taking a column of water from the upper level, whose base was equal to the area of one lock and whose height was 50 feet. The lift would in such a case take a column of water having the same base, but only 6 inches high; or, in other words, it would only take 1 per cent. of the water used by the locks. A chain of locks could, however, be worked so

as to use less water than this, by making the boats wait until several were ready to follow each other in the same direction. Suppose, for instance, that six boats were ready to ascend a chain of six locks with a total rise of 50 feet, and that all the locks were empty. This was a fair assumption, for if the locks were full the preceding boat must also have ascended, and would be one of the series under consideration. The first of the six boats would then take five lockfuls of water from the upper level, and the other five would each take one lockful; or the six boats would require ten lockfuls to enable them to ascend. Now suppose six boats had to descend: of course, finding the locks full, the first would take six lockfuls from the upper level, and the other five would each take one lockful, or eleven lockfuls would be required for the six boats to descend. In other words, for six boats to ascend, and for six afterwards to descend, twenty-one lockfuls would be required, or $\frac{21 \text{ locks} \times 50 \text{ feet}}{6} = 175$ feet. To do the same work the lift would require 6 inches × 6, or 3 feet, that was 1·7 per cent. of the water necessary for the locks, and it would obviate all loss of time from boats having to wait for each other. Mr. Bramwell had, he thought, overstated the possible danger from anything occurring to the presses. The troughs always travelled up and down very fast, and though there might be an important leak in a press, or one of the joints might give way, the trough would only come down a little faster than usual, but he did not think that the consequences would be serious. He could not imagine that a press would burst suddenly; and as the press was in the centre, the trough would always come down horizontally and fall into the water, making, no doubt, a splash, but most probably doing no other mischief. This danger was, however, provided for by having strong presses, and also by having a ready means of testing the apparatus periodically, by loading the troughs with an extra quantity of water when at the bottom of the lift. The danger to life could never be so great as that constantly incurred in hotel lifts. Referring to Captain Galton's remark, as to the extent of the adaptability of lifts to canals instead of locks, no doubt for small differences of level locks were cheaper. If, however, the canal systems of England had to be rearranged, these lifts would play an important part, as they were pre-eminently useful for saving water; and even where water was abundant, the lift still saved a great deal of time. If the lift were made single with a large accumulator, the cost would probably be less than for a double lift, and it might be adopted with advantage where great traffic was not expected.

March 28, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

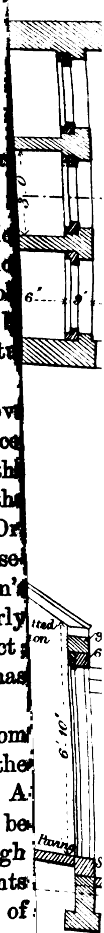
No. 1,474.—"Sewage Interception Systems, or Dry-Sewage Pr cesses." By GILBERT RICHARD REDGRAVE, Assoc. Inst. C.E.[1]

"IT has long been amongst the most fixed of the certainties whi have relation to civilised life, that, wherever human populati resides, the population cannot possibly be healthy, cannot possib escape recurrent pestilential diseases, unless the inhabited area made subject to such skilled arrangements as shall keep it habit ally free from the excrements of the population."[2]

The Author feels that, in basing his observations upon the abov quotation from the writings of an able exponent of sanitary scienc he cannot too early express the obligations he is under to th medical officers of the Local Government Board for much of th information which he now brings forward. In the Reports of Dr Buchanan and Mr. J. Netten Radcliffe in 1869, and in the subse quent Report of Mr. Radcliffe in 1874, together with Mr. Simon's Report on "Filth Diseases," dated July 1874, will be found nearly all the facts needed for the thorough investigation of the subject; and it is from the above sources that the following information has mainly been derived.

For the continuous and rapid removal of the excreta from populous districts, there can be no two opinions concerning the advantages to be derived from the use of water as a carrier. A theoretically perfect system of sewage removal would probably be one where a large volume of rapidly-flowing water, passing through the town in impervious open culverts, received from points situated immediately above it, the dejections, liquid and solid, of the entire population, and carried them at once into large rivers, not used for drinking purposes, or direct into the sea.

As a modification of this, which would be a most wasteful plan, and which would almost necessitate that privies should be outside



[1] The discussion upon this Paper was taken in conjunction with the succeeding one, and occupied portions of three evenings.

[2] *Vide* Twelfth Report of the Medical Officer of the Privy Council, p. 17 (1869).

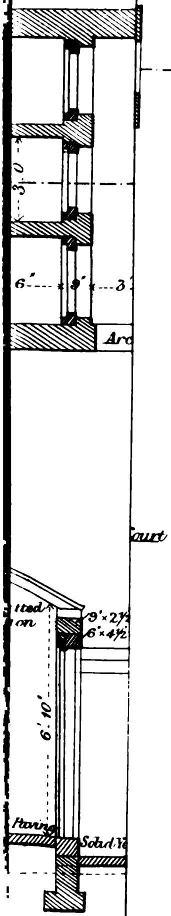
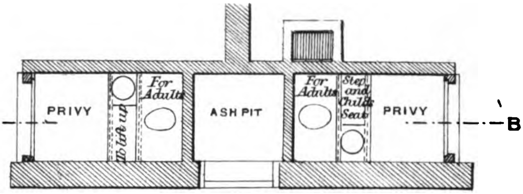
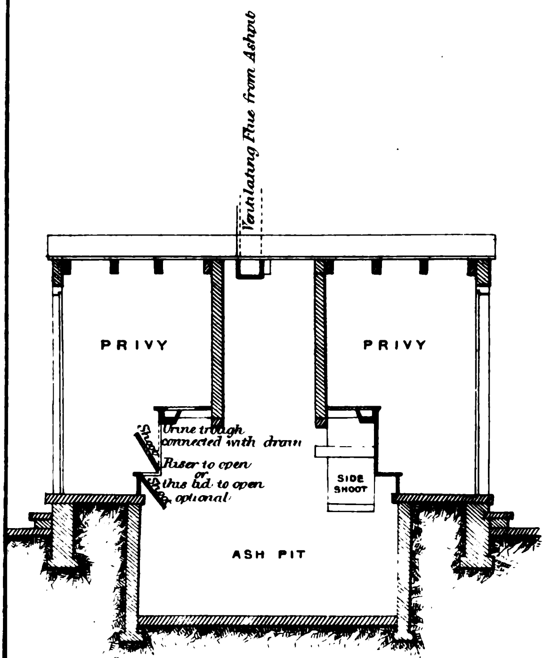


Fig. 6.



PLAN



SECTION A. B.

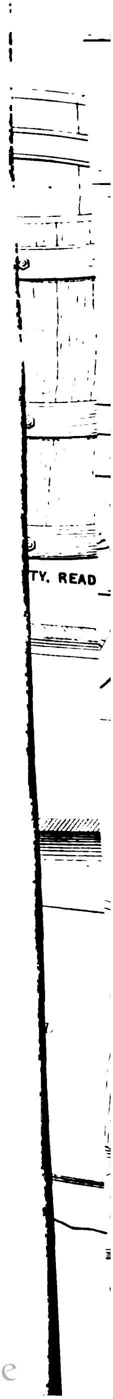
MIDDEN CLOSET USED AT STOCKPORT.

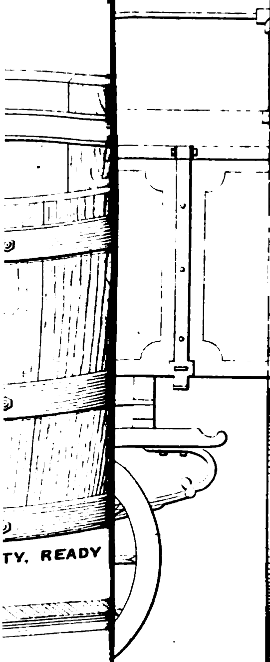
HAM.

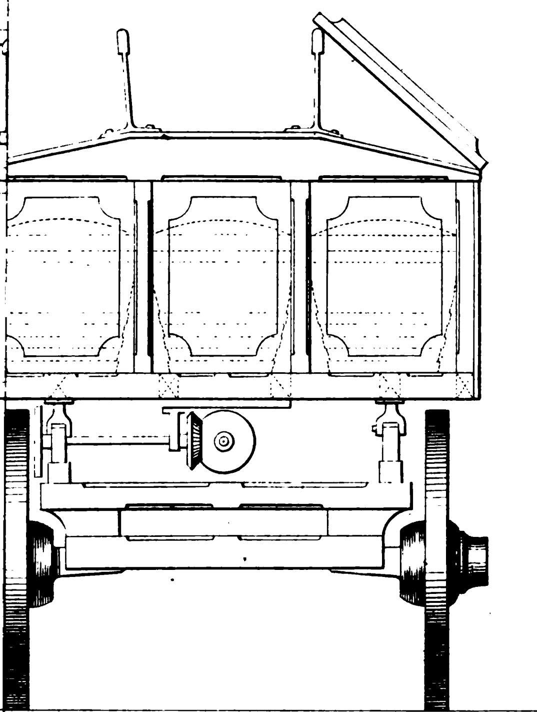
NLEY.

15

Session 187


TY. READ

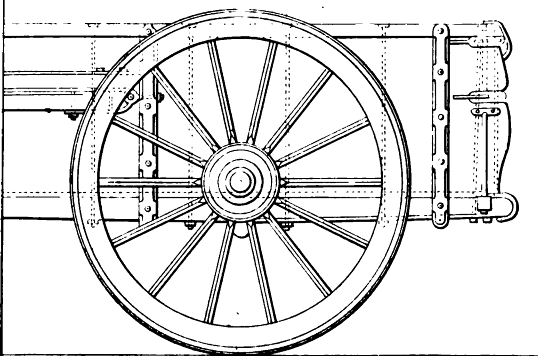




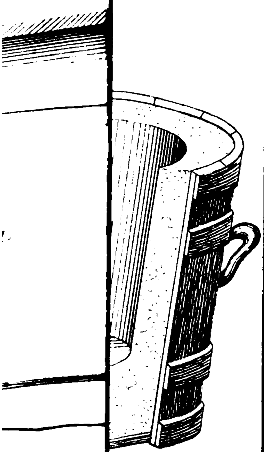
S

END ELEVATION OF NIGHT SOIL VAN.

Fig: 11.



ASH CART.



CLE.

LINED

76. Part 3.

THOS KELL, LITH 40, KING ST COVENT GARDEN


EVATIO
FLOO

PLATE 5.

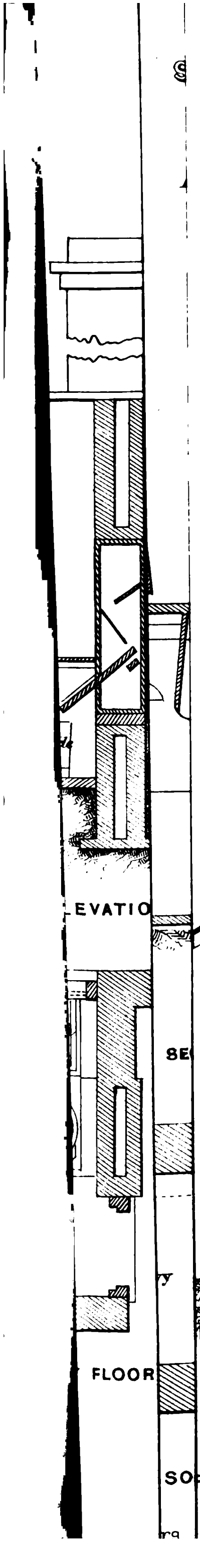
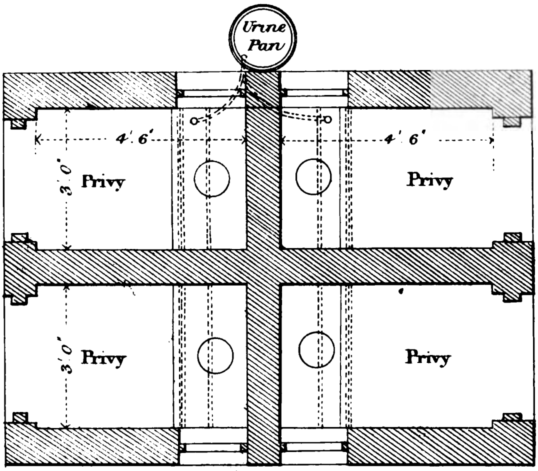
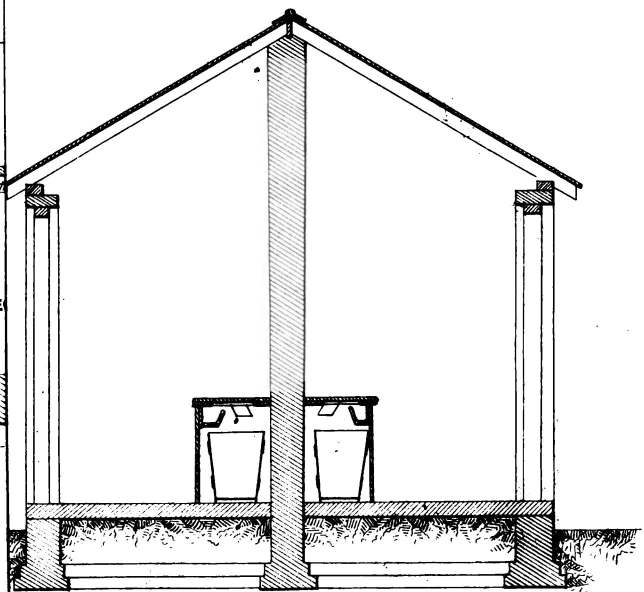


Fig. 16.



PLAN



SECTION

Scale, 4 Feet to an Inch

PAIL SYSTEM WITH SEPARATE URINE COLLECTION.

dwellings, the modern water-closet has been introduced. This contrivance enables the privy to be removed into the interior of houses, and effects a vast saving in the water supply. Even this plan, however, implies the fouling of a large volume of water. Moreover, it brings with it many evils in the shape of concealed drains and sewer gases; and it is a system eminently unsuited for poor and ignorant populations, owing to its complicated machinery, and its liability to derangement and abuse.

Lastly, there is the water-supplied trough or tumbler-closet, which can be so arranged as to be entirely self-flushing, which needs no movable machinery, and which reduces the amount of water to be fouled to a minimum. Mr. Simon says concerning this plan that, managed or constantly superintended by the local authority, it seems the best of all yet discovered privy contrivances for the uncivilised quarters of towns.[1]

In whatever manner water may be employed for the removal of the excreta, a vast quantity must be rendered impure; and great expense is entailed upon towns where an endeavour is made to defecate and purify such polluted waters before they are finally discharged into rivers or into the sea.

The Author leaves entirely out of consideration all sewage processes involved in the use of water as a carrier, and invites discussion rather upon the contrivances in common use in so-called cesspool and midden towns, where a system of interception or some variety of dry-sewage process is employed.

Many towns are so situated that a water-carriage system for the removal of the excreta is almost an impossibility; and there are large towns where, even when a system of drainage has been carried out at enormous cost, the difficulties of dealing with the polluted waters at the outfall appear so insuperable, that a return to the pre-existing midden system, or to some form of interception, has become almost a matter of necessity.

In connection with the proposed subject it may be as well, in the first instance, to draw attention to the fact that, even where a water-carriage system prevails in any town, some plan of removing house refuse, ashes, and dust, some 'dry system' of collection, must also be in force; while an 'interception system,' however carefully it may be carried out, still leaves a vast quantity of slop water and surface drainage to be cleansed and defecated at the outfall.

[1] *Vide* Reports of the Medical Officer of the Privy Council and Local Government Board. New Series, No. II., p. 36.

Indeed, the Rivers' Pollution Commissioners, in their First Report, after a careful comparison of thirty-one towns, in fifteen of which the midden system prevailed, while sixteen were water-closet towns, came to the conclusion, upon somewhat false premises, that it mattered little, as regards the degree of pollution in the sewer water, whether a system of interception was practised or not. They say: "The retention of the solid excrements in middens is not, therefore, attended with any considerable diminution in the strength of the sewage, although the volume even in manufacturing towns is somewhat reduced."[1]

This state of things must, to a great extent, be brought about by leaky and pervious cesspools, absence of proper urinals, ill-paved roads, and the filthy habits of the population generally, and might be reduced to a minimum by careful scavengering and strict supervision, both of which duties must be uncompromisingly and carefully performed in all towns and areas where cleanliness is sought after and enforced.

The term 'interception' implies the exclusion from the sewers or drains of all fæcal matters, and the possibility of interception involves the existence of a system of sewers, which may, however, have been laid down for the removal only of surface water and slops. Five-sixths of the population of this country are dependent upon some form or other of middens or cesspools for the reception of their excreta; and only in a few large towns, and in these only within the last few years, have efforts been made to remedy the defects and nuisances which appeared to be inseparable from the midden system.

The Author proposes to deal with the subject under four heads:—

I. The existing Plans of Sewage Interception—

(a) By various forms of middens, and by middens of improved construction;
(b) By boxes, tubs, and pail-closets;
(c) By earth, ash, and charcoal-closets.

II. The Sanitary Aspect of Sewage Interception.
III. The Commercial Aspect of Sewage Interception.
IV. General Conclusions respecting Dry-sewage Processes.

It is unnecessary to do more than glance at the old-fashioned pattern of midden-closet, with a fixed receptacle. It can only be spoken of, in the language of Mr. Radcliffe, as "the standard of all

[1] *Vide* Rivers' Pollution Commission (1868). First Report, vol. i. (1870), p. 30.

that is utterly wrong"[1]—constructed as it is of porous materials, and permitting free soakage of filth into the surrounding soil; capable of containing the entire dejections from a house, or from a block of houses, for months and even years; uncovered and open to the rain, the wind, and the sun; difficult of access for cleansing purposes, and wholly unventilated and undrained. Of this foul and disgusting type there are only too many examples in all old towns; and midden-closets of this description prevail almost without exception throughout the manufacturing districts. It will hardly be credited that in the year 1871 there were in Birmingham 13½ acres of space devoted to middens, "practically open to the air."[2]

The first step towards improvement in midden construction is to provide a roof or covering to keep out the wet; and when this is done, precautions should at the same time be taken to insure efficient ventilation through safe channels, that is to say, other than through the privy seat. The old tunnel middens of Liverpool were among the worst types of covered middens. Thus, in the First Report of the Rivers' Pollution Commissioners, mention is made of a single midden 160 feet in length by 6 feet 4 inches in height, and 3 feet in width, entirely devoid of egress for foul gases excepting through the privies.

A further stage of improvement consists in rendering the midden impervious, by constructing it of non-porous materials, and in furnishing a drain to carry off the excess of liquids. The next advance in the right direction shows some simple arrangement for deodorising the contents of the midden with ashes, or some other cheap deodorizer; while the form is modified to permit this to be accomplished readily, and to render it capable of being easily cleansed. As instances of such improvements, Plate 3, Fig. 1, shows the midden privy used at Nottingham, and Fig. 2 the modification of this form of privy adopted at Stamford. In these examples the receptacle is concave, in order that the dejections may gravitate to the centre, and the brickwork is carefully cemented on the inside, to render it impervious. There is also a special opening through which ashes may be thrown on the excreta, and a shaft is carried up for ventilation. The riser of the seat is of brickwork, or in the Stamford example of 2-inch stone; the floors also in both cases are of non-porous materials. The Stamford model is the

[1] *Vide* "Report on Certain Means of Preventing Excrement Nuisances in Towns and Villages." Reports of the Medical Officer of the Privy Council and Local Government Board. New Series, No. II., p. 144.

[2] *Vide* Report of the Public Works Committee on the Sewage Question, 1871, p. xi.

better of the two, for in this instance the seat is hinged, so as to throw up and permit of the ashes being sprinkled on the freshly deposited excreta, and as the pit is shallower, it necessitates more frequent cleansing. The Burnley midden of glazed stoneware, Fig. 3, is provided with an overflow pipe connected with the sewers, and is a good type of a drained, non-porous receptacle. The cost, moreover, is small, only 18*s*., and the danger of leakage is avoided.

Another important advance is gained when the size of the midden is reduced to a mere space under the privy seat: this space should be formed of non-porous materials, and be furnished with a ready means for the removal of its contents. Here entirely changed conditions are arrived at with respect to the removal, which, in middens of this class, must take place at the shortest possible intervals. This alone is an immense improvement upon systems which involve the storing of considerable quantities of putrefying excrement for long periods of time in the midst of crowded populations. The middens in use at Manchester and at Hull are shown in Figs. 4 and 5, and are selected as good specimens of this class. The Manchester midden, now to a great extent superseded by the pail-closet, has a glazed earthenware sloping bottom, with a door conveniently placed for emptying the contents. The emptying takes place fortnightly. This type is known as the "bevel-midden." The Hull closet is similar in arrangement, but the stone floor falls in the opposite direction, and the midden, being less capacious, has to be emptied weekly. The emptying takes place from the front, in lieu of from the side, as at Manchester, the riser of the seat being made movable for the purpose; and as the excrement must be removed through the privy, the plan is defective. The Hull midden, moreover, has no air shaft, which is certainly a drawback: the flue for ventilation in the case of the Manchester privy has, by the bye-laws, to be carried up 3 feet above the eaves of the houses.

From privies of this kind the transition to those with movable receptacles is a natural one, and, in accordance with the shape and size of this receptacle, such privies are called tub, pan, or pail closets. In the simplest arrangements of this type merely a wooden box is placed under the seat for the reception of the excreta; this box when full is tipped into the scavenger's cart, and replaced under the seat. Such was the system in use at Nottingham several years back, and this plan still prevails in some districts in Leeds. At Bilston a fresh box is placed under the privy seat; the full one being carted away to the depôt to be emptied and cleansed. This is a further step in the right direction, and is now almost universally practised when a pail system is employed.

A suggestive midden contrivance is in use at Stockport and in some parts of Leeds. Here, as shown in Fig. 6, a trough is placed under the front part of the seat for the purpose of conveying away the urine to a separate receptacle, or direct to the drains. By this means not only are the midden contents kept much drier, and an entire immunity is secured from splashing, but a smaller quantity of deodorizer for the solids can be employed, and considerable freedom from offensive smell is secured. Urine rapidly undergoes putrefaction, and this process is attended by the production of myriads of living organisms, chiefly vibrios and bacteria, which at once bring about a similar change in all organic matter with which they come in contact. The advantages arising from the separation of the liquid from the solid dejections are therefore most important, from the sanitary as well as from the economical point of view, and when this plan is extended to the pail system, it greatly facilitates the carriage of the tubs, and increases the manurial value of the contents.

The difficulty of cleaning out the angles and corners of the boxes at first made use of, and their non-adaptability to closets of different shapes, led to the employment by preference of oval or round tub-shaped receptacles, which had long been used on the Continent. This was partly due also to the introduction of the invention of M. Goux, patented in this country about six years ago, and this plan was the forerunner of the Rochdale and Manchester pail systems. The company formed to work the Goux patents made use, in the first instance, of oval tubs of the form and dimensions shown in Plate 4, Fig. 7. Before placing these tubs under the closet seat, they were lined with some absorbent refuse material. The lining was adjusted and kept in position by means of the core or mould, which was allowed to remain in the pails until just as they were about to be placed under the seat; the core was then withdrawn, and the pail was left ready for use. This system has been tried at Salford and at Rochdale, and is now in use at Halifax and at Aldershot Camp. The proportion of absorbents in a lining 3 inches thick to the central space in a tub of the above dimensions would be about 2 to 1; but unless the absorbents are dry, this proportion would be insufficient to produce a dry mass in the tubs when used for a week, and experience has shown that after being in use for several days the absorbing power of the lining is already exceeded, and the whole contents have become liquid.

There would appear to be but little gain by the use of the Goux lining as regards freedom from nuisance, and though it removes the risk of splashing and does away with much of the unsightli-

ness of the contents, the absorbent, inasmuch as it adds extra weight, which has to be carried to and from the houses, is rather a disadvantage than otherwise from the manurial point of view. The great superiority of all the pail or pan systems is due to the fact that the interval of collection is reduced to a minimum, the changing or emptying of the receptacles being sometimes, as at Edinburgh, effected daily, and the period never exceeding a week.

After a trial of the Goux process the Rochdale authorities introduced a pail system similar in every respect, but omitting the absorbent lining to the receptacles, and under the able management of Alderman Taylor, Rochdale has become a model town, as respects the mode of dealing with its excreta. The Author proposes to describe the system somewhat in detail, because the plan adopted has served as a pattern to other towns, and because there are indications, in the success that has been attained, that this mode of dealing with human excreta may lead the way to the profitable utilisation of sewage. The tubs employed consist of a paraffin cask cut in half and supplied with handles. A strong cast-iron rim (Fig. 8) is fixed on the inside of the tub about 3 inches down, to form a stop for the lid. The cost of a tub so prepared is 4*s.* 9*d.* Galvanised iron tubs have also been tried; but as their first cost, 9*s.* 6*d.*, is double the price of the wooden ones, and as they only last about half the time, the advantages they possess in point of being lighter and more easily cleansed than the wooden ones, and the fact of their being of considerably greater capacity, do not sufficiently counterbalance these drawbacks. At Birmingham, however, galvanised tubs (Fig. 9) costing 10*s.* each are in general use.

The privies in Rochdale are all numbered consecutively in a district register, and a systematic collection from each of the six districts into which the town is divided for this purpose is carried out. By a well-arranged mode of book-keeping, the carters and collectors are checked in their work, and any omission is at once ascertained. The whole of the work is done in the day-time, and every closet is emptied weekly. The privies are provided with a door giving access to the space under the seat, and when the tub is removed it is at once covered with a lid and placed in a van (Fig. 10), while a clean tub having in it a small supply of disinfecting fluid is substituted for the full one taken away. The cost of the collecting van is £47; it is contrived to hold twenty-four tubs: each van makes five journeys a day. In 1874 five such vans in full work collected weekly from three thousand three hundred and fifty-four privies in all parts of the town.

Another feature of the Rochdale system is the separate collection of the ashes and house refuse. A special tub is set apart for this purpose for every house. It stands under a covered shed, and is provided with a hinged flap for a lid. A cart, the cost of which is £25 (Fig. 11), is employed for the collection of the ashes. This cart accompanies the van in its rounds, so that the removal of the ashes and the excreta is conducted simultaneously. Three such carts, in full work, collected weekly in 1874 from three thousand three hundred and fifty-four ash places throughout the town.

Alderman Taylor has carefully investigated the expense of the collection of the ashes and excreta in a separate form, and from his figures the following table has been drawn up. The figures relate to the collection in 1875.

Weight of excreta collected weekly	96 tons.
" ashes " "	161 "
Total weight	257 "

Number of pails of excreta collected weekly 5,082

$$\frac{96 \times 2240}{5082} = 42 \text{ lbs. average weight per pail.}$$

The expenses of collection, exclusive of wear and tear, interest on capital, and depreciation, are:—

	£.	s.	d.
15 horses at 20*s*. per week	15	0	0
Pay of 30 carters and collectors	33	15	0
Total	48	15	0
Proportionate cost for the collection of the pails containing excreta	27	8	0
" " for collection of ashes	21	7	0
	48	15	0

Cost of collecting 5,082 pails, £27 8*s*. = 1·294*d*. per pail per week, or 5*s*. 7*d*. per pail per annum.

Population using pail system, 50,000.

		d.
Cost per head per annum for excreta therefore	=	6·84
" " " ashes "	=	5·33
Total annual cost per head for collection of ashes and excreta	=	12·17

This estimate agrees closely with the observed cost in other towns, and it may be assumed, with reasonable accuracy, that the annual cost to a population for the removal of its ashes

and excreta on the dry system will be about £50 per 1,000, or 1*s.* per head; from this sum the amount realised by the sale of these substances as manures has not been deducted. The Rivers' Pollution Commissioners found that the cost of removing the ashes and excreta, collected on the dry system, from nine important towns in South Lancashire, inhabited by one million one hundred and ten thousand persons using one hundred and thirteen thousand privies, and amounting in the aggregate to 347,000 tons of manure, was little less than 1*s.* per head per annum, and realised rather less than 5*d.* per head of the population. There might be perhaps a slightly increased cost, as indicated by Alderman Taylor's figures, in a separate collection of the ashes and excreta, but the advantages accruing from keeping these substances apart would far outweigh this, when the question of manure-making comes to be dealt with.

Those simple closet arrangements have next to be considered where an attempt is made, injudiciously in many instances, to deodorise the excreta by the application of absorbent material, such as earth or ashes. A closet of this kind may or may not be associated with the pail system. At Manchester, where a form of ash-closet is extensively used (Plate 5, Fig. 12), a cinder-sifter attached to the privy is combined with a pail receptacle. The sifter is so arranged that the fine ash is directed by a shoot on to the excrement, while the cinders fall into a bucket whence they may be taken for re-burning. Various materials have been tried for the sifters, and zinc perforated with ½-inch holes is now used, as it is found least liable to clog. Mr. Radcliffe says, with respect to an inspection of the Manchester ash-closets, that "great differences were in consequence observed in the quantity of exposed excrement, and some differences in the fæcal smell. But where least care had been taken, and also where the pail contained simply the uncovered excrement of several days' accumulation, the fæcal odour was inconsiderable."[1] It would appear from this that there is little to be gained in point of deodorisation by the use of ashes as at present practised. As will be shown later, the true plan of employing ashes or other deodorizers is to apply them in small quantities to the solid matters in a vessel from which the liquids have been excluded.

Probably the best known contrivances for deodorising and disinfecting the excreta deposited in dry closets are those in which advantage is taken of the deodorising properties of dry earth,

[1] *Vide* "Report on Certain Means of Preventing Excrement Nuisances in Towns and Villages." Reports of the Medical Officer of the Privy Council and Local Government Board. New Series, No. II., p. 184.

so prominently associated with the name of the Rev. Henry Moule. In Mr. Moule's closets a supply of earth, contained in a hopper behind the seat, is thrown on to the excreta as deposited, by the action of an ordinary pull-up handle, similar to the pull of a water-closet, or by the weight of the user on a balanced seat or footboard, or by both combined.

Dr. Bond has patented an ingeniously-arranged dry closet, wherein the vessel, fixed beneath to contain the dejections, is so constructed as to receive the liquids and solids into separate compartments. A box for the supply of the deodorising material, consisting of sifted ashes, is attached to the lid (Fig. 13), and the person on entering the closet raises the lid and distributor, and by so doing measures out a charge of the deodorizer; on leaving the seat he closes the lid, and by this means discharges the ashes over the solid excreta.

In Moser's "universal closet" a supply of the deodorant, stored in a chamber at the back of the seat, is spread over the dejections in measured quantities by a pair of bellows actuated by means of a lever handle. In this closet the urine is diverted by a shield or "urine guard" into an independent vessel containing absorbent material.

In Gibson's dry closet a movable shoot attached to a hopper receives a small quantity of the deodorizer, and distributes it on to the excrement by an action similar to that of a shovel. Mr. Gibson has also a stand-pipe with a funnel mouth (Fig. 14), so situated as to receive the urine and convey it direct to the drain, without mingling with the solid excreta. All such contrivances as this aim at economising the quantity of the dry deodorizer, and if the user of the closet can be trusted to avail himself of mechanical means for deodorisation he will, probably, be just as likely to avail himself of a supply of dry material, situated conveniently for the purpose, to be thrown on the dejections with a hand scoop. All mechanical devices for the distribution of deodorizers which the Author has yet seen, even including the simple ash-sifter at Manchester, are more or less liable to get out of order, and are ill adapted, therefore, to "uncivilised populations." With reference to the separation of the liquids and the solids and the use of earth or ashes, it has been conclusively shown that, to absorb the urine and deal with the excrement of an average population, a daily supply of earth amounting to 4½ lbs. per head will be required; and when this quantity comes to be used for a large population the cartage to and from the depôts will be enormous. When the urine is separately stored, there still remains the difficulty of

dealing with it, unless, as Mr. Gibson proposes, it is allowed to run direct into the sewers.

In ash and charcoal closets similar arrangements to those already examined in the case of dry-earth closets as a rule prevail.

Animal charcoal forms such an excellent deodorizer, that when the urine is kept apart from the fæces, from ½ oz. to ¾ oz. suffices, if carefully distributed after each use of the closet, to remove all disagreeable smell from the solids. This is an important consideration when the cost of collection and carriage has to be dealt with, and indicates the right way of using deodorizers. The Carbon Fertiliser Company has devised a first-rate separator-pail, for keeping the liquids apart from the solids (Fig. 15). The object is effected by a horizontal perforated diaphragm, which retains the fæces, but allows the urine to pass through into the lower part of the receptacle. This plan of separation is the only one that answers, where the chamber slops are also thrown into the pails.

The sanitary bearings of dry collections have next to be considered; and upon this point medical testimony, while it is unanimous in condemning the dangerous and disease-spreading character of the old unimproved midden of the accumulative type, tends conclusively to prove that, under a well-managed tub or pail system, nearly all the former objections to a dry process are removed. Messrs. Radcliffe and Buchanan say in their Report, dated 1869, dealing with this subject: "It is impossible not to be struck with the advantage that a tub or pail system has in relation to diseased excrement. The facility and thoroughness with which any required chemical disinfection may be done, and the way in which the excrement itself can be wholly got rid of, leaving none of its products behind—nothing soaking into the ground, or hanging about middenpits or sewers—obviously suggest most important powers possessed by this system for preventing spread of the excremental diseases."[1] This, it must be remembered, is an advantage common to no other method of dealing with excreta, and is one rendered peculiarly valuable by the increased knowledge respecting the propagation of diseases of the typhoid class.

All authorities are unanimous also in declaring that the pail system, when properly carried out, as at Rochdale, reduces the excrement nuisance to a minimum, and both in those towns that have come under the Author's personal observation, and from the evidence gathered from the inhabitants themselves, little inconvenience is caused either to sight or smell by the use of the tubs

---

[1] *Vide* Twelfth Report of the Medical Officer of the Privy Council, p. 138 (1869).

or pails, or by the mode adopted for changing or collecting them. From the sanitary point of view Mr. Simon's testimony is of the highest value, and this gentleman pronounces respecting dry processes as follows: "That, failing a water-system, both large and small populations can obtain under other and amended systems of privy-management a complete or comparatively complete freedom from excremental nuisance and injury."[1]

But it is from the commercial aspect that the dry system of dealing with human excrement presents its most important advantages, and if ever the manufacture of manures from excreta is to become a source of profit—and it is impossible to doubt that it ere long will do so—it will be effected by a proper treatment of pail-carried excreta. In spite of all that Stock Exchange sewage companies may urge to the contrary, experience has repeatedly demonstrated, that when once the valuable manurial components of the excrements have been diluted with 100 times their weight of water, the only method of utilising the liquid as a manure is to apply it in definite quantities to properly-prepared land; though even when this is effected under the most favourable circumstances, there are no evidences that a profit can thus be obtained from sewage. When, however, the liquid and solid dejections, collected free from admixture with foreign substances, and in an undiluted form, have to be dealt with, the question of their profitable utilisation is placed upon a different footing. When, moreover, by the employment of closets of some such construction as that shown in Fig. 16, the collection of the liquids and solids can be carried out in separate vessels, the possibility of making a profit by the manufacture from the excreta of solid manures may be predicted with certainty.

From careful observations of the quantities of excreta collected in pails, it may be assumed that each individual of an average population will yield 1 lb. of mixed pail sewage per diem, or 3¼ cwt. per annum. The cost of carrying this quantity to a depôt is, in accordance with the Rochdale estimate, 6·84*d.* per head, or say 3*s.* 6*d.* per ton. Allowing for interest on capital and depreciation on works and plant, it will not be far wrong to assume the cost of the pail stuff, delivered at the wharf or depôt, at 4*s.* per ton. By processes familiar to chemists, this ton of pail sewage, the produce of 6·16 average individuals, is found to possess in the form of a finished manure a value, in round numbers, of 16*s.*

[1] *Vide* Reports of the Medical Officer of the Privy Council and Local Government Board. New Series, No. II., p. 34.

That is, the theoretical annual value of the fæces, and that portion of the urine voided with the fæces, of an average population amounts to a little over 2*s.* 6*d.* per head, while the average value of the whole of the excreta has been variously estimated at from 8*s.* to 10*s.* per head per annum.

General Scott, C.B., Assoc. Inst. C.E., who has devoted great attention to the production of manures from dry sewage, has recently demonstrated that from the liquid and solid dejections collected on the pail system it is possible to prepare, at a reasonable profit, concentrated manures containing from 5 to 6 per cent. of ammonia and from 8 to 10 per cent. of phosphoric acid, and which would therefore command a market value of from £7 to £8 per ton, and upwards. Manures of this class are sold at prices approximating to their theoretical value, *i.e.*, their value as indicated by chemical analysis; while feeble manures, such as those prepared from sewage sludge and the contents of ordinary ash-pits and middens, rarely fetch more than from one-fourth to one-tenth of their theoretical value. It would take about 10 tons of pail sewage to produce 1 ton of the above-described concentrated manure, or each ton of such manure would be the annual produce of sixty-two average individuals. As will readily be understood, when the excreta are largely mixed with earth, charcoal, or ashes, which give weight and bulk without value, the possibility of producing high-class manures becomes out of the question. Here is at once the reason why all the poor manures, made from mixtures of excrement with what have been termed "profligate associates," are sold with difficulty, and rarely fetch more than a few shillings per ton. Efforts to obtain more concentrated mixtures have from time to time been attended with fair success. The Author has lately inspected the Paris Municipal Works at Bondy, where sulphate of ammonia is being made from the liquid contents of the *fosses mobiles* at a small profit. Urine collected separately was some few years back profitably treated at Glasgow for the extraction of carbonate of ammonia; and only last year a company at West Bromwich succeeded in producing a concentrated manure, by boiling down the mixed pail contents to dryness, which commanded £7 10*s.* per ton. The works had, however, to be abandoned on the score of creating a nuisance.

The conclusions formed by the Author upon dry-sewage processes are:—

1. That in towns where, for local reasons, a water-carriage system for the removal of the excreta is impracticable, it is

possible, by a modification of the midden-closet, to effect this removal without nuisance and without injury to health.

2. That the removal of the excrements can best be effected by employing pail or tub closets which provide for the separation of the liquid and the solid dejections, and are emptied at intervals not exceeding one week.

3. That the local authority should conduct the removal of the excreta and also of the ashes, and should regulate this removal by stringent supervision.

4. That it is possible, by suitable manipulation, to prepare from human excreta, collected on the dry system, concentrated manures which will repay the cost of collection and cover all the expenses of their production.

The Paper is accompanied by a series of diagrams, from which Plates 3, 4, and 5 have been compiled.

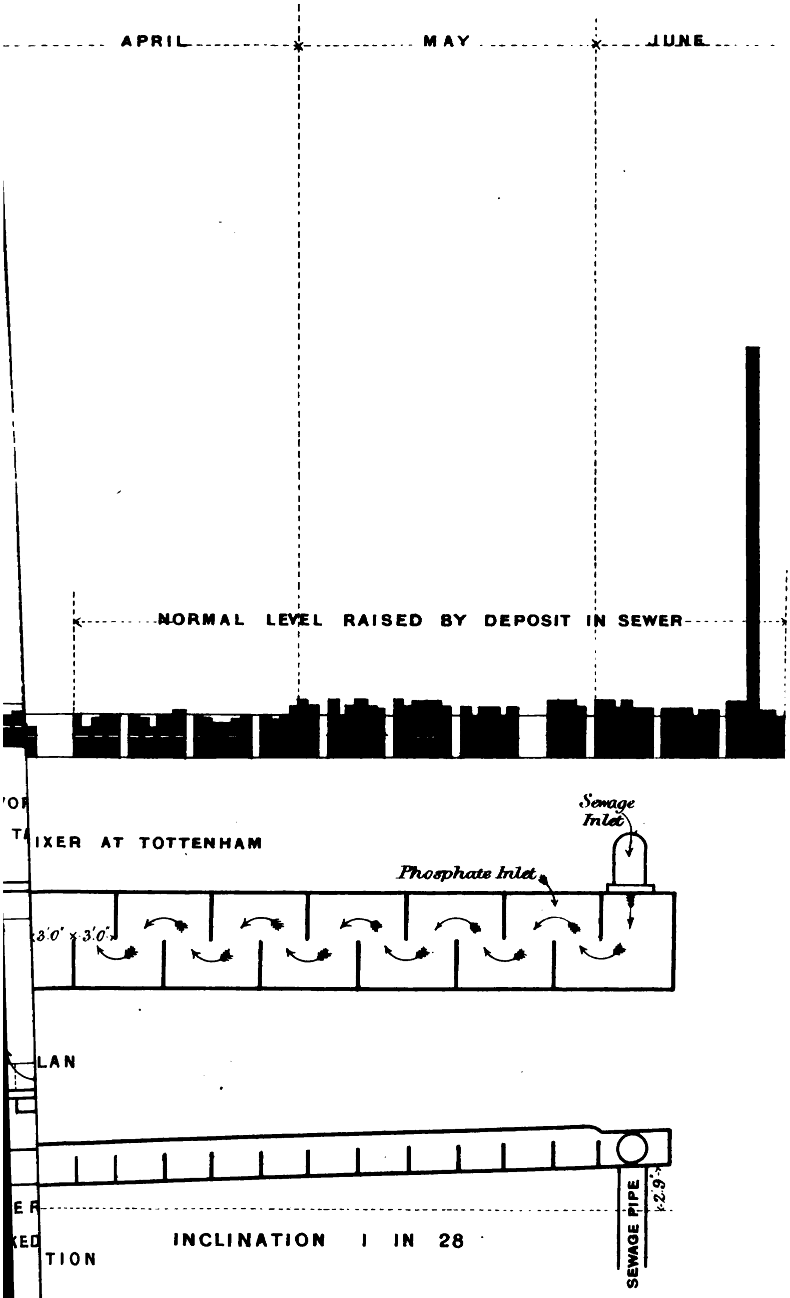
No. 1,475.—"The Treatment of Sewage by Precipitation." By William Shelford, M. Inst. C.E.[1]

Probably no question of practical interest at the present day is more in need of a record of facts, to serve as a basis of future improvement, than the treatment of sewage. In the hope of contributing some useful information relating to the method of treatment known as the 'precipitation' or 'tank system,' the following notes have been selected from those made during several years' professional acquaintance with the subject.

In 1869, 'precipitation' received new life by the publication of a pamphlet, entitled "The Sewage Question Settled," by the Native Guano Company. That pamphlet described the A B C[2] process as then carried on at Leamington, where the company were treating the sewage of twenty thousand persons (600,000 gallons daily), and it stated that, by the use of ½ ton of chemicals, they obtained 5 tons of dry manure per day, at a cost of 30*s.* per ton, including all expenses, even interest on capital. The company showed by analysis that the manure contained 4·2 per cent. of ammonia, and succeeded in obtaining £3 10*s.* per ton for it. The net profit of £2 per ton thus shown, or £10 per day, naturally attracted attention, and the interest was increased by the story told to all comers that the patentee had got the idea of using blood from St. Paul's Epistle to the Hebrews, 9th chapter, 22nd verse, where it is written, "Almost all things are by the law purged with blood." Leamington was a favourable place for the experiment; but time soon showed that the practical difficulties had not been met. Meanwhile the Native Guano Company obtained a concession of sewage from the Metropolitan Board of Works, with leave to erect works at the outfall of the Southern Metropolitan Sewers at Crossness, for the treatment of 500,000 gallons daily, and proceeded to demonstrate their process there. During the erection of the works the £5 shares of the company rose to £40, and the excitement produced by that circumstance, and the constant criticism of the process, led to the Crossness experiment being regarded by common consent, the company scarcely excepted, as a crucial test; the more so because the company put the whole matter under the independent superintendence of the Engineer and Chemist of the Metropolitan Board, whose reports were published in January 1873. These were utterly con-

[1] The discussion upon this Paper was taken in conjunction with the preceding one, and occupied portions of three evenings.

[2] So named from the initials of the principal ingredients—alum, blood, and clay.



THOS KEIL LITH 40 KING ST COVENT GARDEN

demnatory of the pretensions which the company had put forward in their pamphlet, inasmuch as the Engineer, Sir J. W. Bazalgette, C.B., M. Inst. C.E., showed that the cost of 142 tons of manure manufactured at Crossness was £6 6*s.* 4*d.* per ton, "exclusive of rent, interest on capital, depreciation of plant, and other incidental items;" and the Chemist, Mr. Keates, reported that "the value of the manure, as judged by its chemical composition, does not exceed 20*s.* per ton."[1] After every allowance had been made for the poverty of the sewage treated, its small quantity (viz., 14,600 gallons per hour, instead of 20,800 gallons, for which the works were constructed), the cost of lifting the sewage by pumping, the imperfect system of drying, the exceptional cost of chemicals, and other items for which the company might reasonably claim some consideration, it was generally felt that not only was the "sewage question (not) settled," but the more homely problem of making two ends meet could not be solved by the A B C process at Crossness.

That time marks a new era in the history of 'precipitation.' Towns which asked and obtained £500, and even £1,000, per annum for the concession of their sewage have since abandoned their claims; and in a few cases sanitary authorities have agreed to pay small sums for the removal of the nuisance.

Such a collapse has laid the Company open to attacks which were often undeserved, and to blame which was certainly unmerited. There can be no doubt that the company sacrificed itself by submitting to a public test before mastering the facts or acquiring the experience necessary for the application of the process on a working scale. This failure, however, not only affected the company, but was considered a death-blow to precipitation generally, which was so far good that it led to the present opinion of the public with regard to the value of sewage—an opinion which seems to be everywhere finding expression, viz., that whatever the value of sewage may eventually prove to be, no means yet exist by which a profit can be realised from it. Irrigation by sewage has its troubles; filtration of sewage is not wanting in difficulties: yet each system has its advocates. Precipitation is represented by several companies, which are still before the public and have not given up the attempt. Biding their time, they are evidence, if evidence be needed, of the wide field open to a good precipitation process.

It is not proposed in this Paper to advocate, much less to condemn, any process, nor to give a description of all the precipitation processes; but it is desired to bring out the practical points to

[1] *Vide* the "Financier," 22nd January, 1873.

which attention should be given, and to indicate the direction which improvements should take.

It will be convenient to do this under the following heads:—

I. ANALYSIS OF COST OF NATIVE GUANO, AND THE LESSON TO BE LEARNED FROM IT.

II. DESCRIPTION OF MODEL WORKS ERECTED AT BATTERSEA FOR EXPERIMENTS ON SEWAGE WITH MR. DUGALD CAMPBELL'S PROCESS, AND THE RESULTS OBTAINED.

III. DESCRIPTION OF SOME OF THE WORKS ERECTED FOR THE UTILISATION OF THE SEWAGE OF TOTTENHAM, BY WHITTHREAD'S PROCESS, AND THE RESULT.

IV. CONCLUSIONS.

I. ANALYSIS OF COST OF NATIVE GUANO, AND THE LESSON TO BE LEARNED FROM IT.

The Native Guano Company at first stated that at Leamington the cost of manufacturing the manure did not exceed 30*s.* per ton. Sir J. W. Bazalgette reported that the cost of manufacture at Crossness was £6 6*s.* 4*d.* per ton, including pumping the sewage.

The total quantity of manure manufactured at Crossness was about 142 tons, at a cost of £895, divided thus:—

							Cost per ton of manure.					
	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*	£.	*s.*	*d.*
Chemicals . . .	293	16	10				2	1	4			
Manufacturing wages	220	12	2½				1	11	1			
Chemical supervision	33	10	4				0	4	9			
Manufacturing stores	47	13	0				0	6	8			
Total cost of manufacturing, exclusive of engine-power and coals for drying				595	12	4½				4	3	10
Coals	230	11	3½				1	12	5			
Mechanical supervision	38	0	10				0	5	5			
Engine stores . .	14	7	4½				0	2	0			
Total cost of engine-power, including pumping sewage and coals for drying				282	19	6				1	19	10
Sale account — Bagging and loading .	8	15	3				0	1	6			
Office—Wages of boy	7	16	1½				0	1	2			
				16	11	4½				0	2	8
				£895	3	3				£6	6	4

	£	s.	d.	
The quantity of chemicals used was $166\frac{3}{4}$ tons, the cost of which was, as above, £293 16*s.* 10*d.*, or £1 15*s.* 3*d.* per ton. But the chemicals, in the condition in which they were purchased and used, contained about 50 per cent. of moisture, which reduced their weight in the dried manure to 81 tons, and made their cost in the dry state $\frac{£293\ 16s.\ 10d.}{81}$ =	£3	12	6	per ton.
To which must be added the extra labour required for the manipulation of the $166\frac{3}{4}$ tons instead of 81 tons, and the cost of drying the $166\frac{3}{4}$ tons down to 81 tons—say	0	15	0	per ton.
Total cost per ton of the dry chemicals .	£4	7	6	
Deduct this from the total cost of the manure	6	6	4	
And there remains a balance of . . .	£1	18	10	per ton
for every expense but the chemicals and the pumping of the sewage. Again, deduct cost of pumping the sewage—say	0	10	0	per ton of manure.
Total expenses, exclusive of pumping and chemicals	£1	8	10	

Therefore the expense of the process may be taken to be only £1 8*s.* 10*d.* per ton of manure, if the cost of the chemicals is excluded. But inasmuch as the cost of the manure was £5 16*s.* 4*d.*, without pumping the sewage, instead of £1 8*s.* 10*d.*, it is impossible to escape the conclusion, that it was the cost of the chemicals which mainly brought about the failure of the experiment at Crossness.

Turning now to Leamington, the Company stated that ½ ton of chemicals had been used and 5 tons of manure obtained daily at a cost of 30*s.* per ton.

The cost of ½ ton of chemicals would, at £4 7*s.* 6*d.* per ton, as above, be £2 3*s.* 9*d.*, or $\frac{£2\ 3s.\ 9d.}{5}$ = per ton of manure	£0	8	9
Add the other expenses, as at Crossness, but without the cost of pumping the sewage, since it flowed by gravitation through the works	1	8	10
Total cost of manure at Leamington . . .	£1	17	7

Or 38*s.* per ton, as against 30*s.* per ton stated by the Company. It thus appears that the cost of the chemicals at Leamington was comparatively unimportant, and that the Native Guano Company actually had the settlement of the sewage question at Leamington in its hands if it sold the manure at £3 10*s.* per ton.

Although the details of this estimate may be open to exception, the fact remains that it was the chemicals which made the difference between the cost of the manure at Crossness and at Leamington; and it will be worth while now to see how this great difference is to be accounted for.

The ½ ton of chemicals at Leamington was applied, according to the Company's statement, to 600,000 gallons of sewage, which is equivalent to a dose of 1·86 lb. per 1,000 gallons. Many changes appear to have been made, and the dose seems to have been afterwards increased at Leamington, Leeds, and other places until, at Crossness, it reached 31·8 lbs. of moist chemicals per 1,000 gallons. The increase in the quantity of the dose was accompanied also by a great alteration in its constituents and their proportions. They were as follows:—

Chemicals used in A B C Mixture.	Leamington. Parts by weight.		Crossness. Parts by weight.	Dose per 1,000 gallons. Leamington. lb.	Dose per 1,000 gallons. Crossness. lbs.
Alum	95·62	26·77	nil	1·78	13·78
Clay		68·85	43·33		
Blood		1·78	a little	·03	..
Animal charcoal .	2·54	1·91	48·33	·05	15·37
Vegetable charcoal.		·63			
Magnesia . . .	..	·06	nil	·001	..
Salt	..	occasionally	nil	..	..
Permanganate of potash	..	occasionally	nil	..	..
Sulphate of alumina	..	nil	8·33	..	2·65
Lime	..	nil	a little	..	..
		100·00	100·00	1·861	31·80

Thus the principal difference was a large addition at Crossness to the proportion of charcoal used; and this fact will have more significance when the actual quantity is noted, amounting at

Leamington to 0·05 lb., while at Crossness it was 15·37 lbs., per 1,000 gallons. The effluent water at Crossness was reported by Mr. Keates to be "extremely good"; and it was certainly much better than that obtained at Leamington by the above mixture. Possibly the superiority of the effluent water at Crossness was due to the charcoal. If so, the Company would appear to have thought that charcoal could be added in large quantities for the purpose of deodorising both the effluent water and the sludge, as long as the selling price of the manure was arbitrarily fixed at £3 10*s.* per ton without reference to its composition.

The Native Guano Company has doubtless long since learned the lesson, that while a dose of 1·86 lb. of A B C mixture per 1,000 gallons of sewage may leave a profit on manure sold at £3 10*s.* per ton, yet when the dose is increased to 31·8 lbs. per 1,000 gallons it can only result in a heavy loss; or, in other words, that a moderately good effluent may be produced, and a profit may be shown on the manufacture, if the manure will sell for £3 10*s.* per ton, but that it will not pay to produce an "extremely good" effluent by the admixture of a large quantity of precipitants of low manurial value.

II. Description of Model Works erected at Battersea for Experiments on Sewage with Mr. Dugald Campbell's Process, and the Results obtained.

The process known as "Campbell's Patent" was introduced in 1872. It consists in adding phosphate of lime in a soluble state to the sewage as it enters the works, and in precipitating it after sufficient admixture by a further addition of lime. It was worked for six consecutive days in July 1872 at Tottenham, and the results are stated to have been that 3½ million gallons of sewage were treated with superphosphate of lime (made of 6½ tons of bone-ash and 4¾ tons of brown acid) and 4 tons of lime, total 15¼ tons of chemicals. The yield was 22 tons of dried manure, and the effluent water was reported by chemists as "very satisfactory."

The dose of chemicals was 9·76 lbs. per 1,000 gallons, the cost being £57 2*s.* 6*d.*,[1] or £3 14*s.* 9*d.* per ton, and

	£	s.	d.
$\frac{\text{£57 2}s.\text{ 6}d.}{22}$ = ...	£2	11	11
Add other expenses as at Crossness, excluding pumping the sewage, which is not part of the process .	1	8	10
Total cost of manure per ton . . .	£4	0	9

[1] The cost of the chemicals is given as £66 in the Appendix, the difference being due to a higher estimate of their market value, but the margin of £1 per ton, hereafter mentioned, would more than suffice to cover it.—W. S.

The value of the manure was estimated by several eminent chemists at about £5 per ton.

The following is one of the analyses:—

Moisture	19·04
Organic matter containing nitrogen 1·2, equal to ammonia 1·45	15·26
Precipitated phosphate of lime	23·14
Insoluble phosphates	3·80
Sulphate and carbonate of lime, and lime uncombined	19·25
Alkaline salts and magnesia	3·14
Insoluble matter	16·37
	100·00

The manufacture of this manure would thus show a margin for carriage, &c., of about £1 per ton, if the moisture in the chemicals did not exceed that in the manure analysed, viz., 19 per cent.

The works at Tottenham were not then applicable to a continuous treatment of all the sewage by this process, nor were the owners of the patent in a position to execute the necessary additions to them. Moreover, further experience was wanting on several points before applying the process on a large scale, and it was consequently determined to erect small works for experimental purposes.

Permission was obtained from the Metropolitan Board of Works to pump sewage from the Heathwall Sewer, in Battersea Fields, skirting the foot of the rising ground of Clapham Common, and receiving the drainage of a population estimated at about ten thousand. The sewer is egg-shaped, 5 feet by 3 feet 4 inches, and the fall is 1 in 1,800 (Plate 6). It receives surface drainage as well as the house sewage. The minimum depth of sewage is 6 inches, at night, equal to 345,000 gallons per twenty-four hours. The maximum depth in dry weather is 10 inches, equal to 900,000 gallons per twenty-four hours. When filled the sewer delivers 15 million gallons per twenty-four hours.

Observations were taken on the depth three times almost daily, beginning on the 11th of September, 1873, and continuing to the 20th of June, 1874, and again from the 26th of January to the 22nd of May, 1875. The two series of observations gave the same general results (Plate 6). These show, first, that in this sewer there was very little interference by storm water with the ordinary flow; secondly, that the volume of storm water when it occurred was such as to make the treatment of the sewage most difficult on account of the quantity, but at the same time the treatment was unnecessary, because of the extreme dilution of the sewage;

thirdly, that sewage may be treated by precipitation where the gradients of the sewers in the district and other circumstances are suitable, even though it be conveyed by the 'combined' instead of the 'separate' system of sewers.

The rainfall during the observations was, according to Mr. Symons:—

1873.	Inches.		1874. Inches.	1875. Inches.
September . . .	2·46	January . . .	1·18	3·22
October. . . .	2·97	February. . .	0·91	1·06
November . . .	1·87	March . . .	0·39	0·69
December . . .	0·48	April. . . .	1·26	1·53
		May	1·14	1·61
		June	2·05	—

Both 1873 and 1874 were dry years, the total rainfall in London being 22·67 inches and 18·82 inches, as against the average of 25·68 inches.

The sewage was generally fresh, but it sometimes suddenly became foul. On some occasions it was loaded with suspended matter, chiefly sand, and on others it was almost clear water. But it was at all times what might be called a weak sewage.

One of the arches in the viaduct of the London, Chatham, and Dover railway was hired, and works were erected for the treatment of a maximum quantity of 5,000 gallons per twenty-four hours. They consisted of—

1. An ordinary hand pump for raising the sewage.
2. Two mixers worked by a continuous shaft from the hand pump, so arranged as to prevent the subsidence of the chemicals in the water with which they were mixed, and at the same time to bale the due proportion of each into the sewage.
3. A mixing trough ('salmon ladder') for effecting the admixture of the chemicals with the sewage (Plate 6).
4. A series of six concrete tanks for the precipitation (Plate 6).
5. A series of filter beds for partly drying the sludge.
6. A Milburn's drying machine for completing the dried manure.

The two mixers were an adaptation of the water-wheels employed in Alpine rivers for raising water by buckets attached to their rims. Each of them consisted of a wheel which revolved in a suitable vessel containing the chemicals, diluted with water, at a sufficient velocity to prevent their subsidence, and at the same time by means of cups attached to the ends of the spokes the right quantity of each chemical was raised and thrown into the 'salmon ladder' containing the sewage. These mixers have always worked well, and have given no trouble.

The mixing trough, made like a 'salmon ladder,' was first applied by the Author to these works, and was found to be so convenient and economical, that he afterwards used it on a large scale at Tottenham (Plate 6).

The tanks were arranged similarly to those for the works at Crossness. They were capable of use for the treatment of the sewage either during its continuous flow through them, or by intermittent flow into each, and then allowing the sewage to remain at rest during precipitation, but without stopping its flow into the works. Each tank was a cube of 4 feet, and held about 415 gallons. The series of six held 2,500 gallons, or twelve hours' flow of sewage. When worked by 'continuous flow' the two first tanks are used alternately and receive most of the precipitate. From these the flow of the sewage is directed through the remaining four, but any one of them can be emptied and cleaned by shutting it off with sluice boards. When worked by 'intermittent flow' the tanks are filled, and after a proper lapse of time for the deposit are cleaned in succession. One advantage of this arrangement of tanks is economy in first cost. It is evident that if one tank were used for twelve hours' flow a duplicate must be provided during cleansing.

On the other hand, the series of six could be kept equally clean by providing only one-sixth more tank-room. It has further the advantage of concentrating the precipitate in a small space, by which means it can be more cheaply removed, and the necessity for removing it promptly is greater than if it was spread over the surface of a large tank. The works are thus frequently cleansed —an important point, too little attended to in precipitation processes. The sludge or precipitate is discharged from the bottom of the tanks into a channel communicating with the filter beds.

The filter beds for partly drying the sludge were of the commonest description. They have worked satisfactorily, and have been used by the Author on a large scale at Tottenham with equally good results.

Milburn and Company's machines for drying sludge were also adopted at Tottenham, where they gave results which will be interesting. Suffice it to say now, that the small machine made for these works was quite satisfactory in its operation, and, after allowing for certain disadvantages inseparable from its diminutive size, equally so in its results.

These works have been in operation, under the name of the "Model Works of Campbell's Patent Manure and Sewage Company,

Limited," since September 1873. Thirty-one experiments were made from that date to the 12th of May, 1875, during which period 155,000 gallons of sewage were treated. They have since been intermittently in operation as occasion required.

Numerous experiments were made to determine the best proportion of chemicals to be used, and eventually that found to produce a good effluent water of greater purity than would pass what is known as the "Thames Conservancy Standard" was a dose of 10 lbs. of superphosphate and 3 lbs. of lime, or a total of 13 lbs. of chemicals per 1,000 gallons. The effluent water as it left the works was either neutral or gave a slight alkaline reaction, and was more suitable for irrigation purposes than raw sewage.

The precipitate, or sludge, when run upon the filters, contained 90 per cent. of water and was about 1 foot deep. The heavier matter at once subsided and left the water on the top; but in consequence of the absence of clay, and the porous condition of the sludge, the water percolated through both it and the filter, until a comparatively solid stratum of sludge, of the consistency of mortar, was left. The filters were found to work best when the partially-dried sludge did not exceed 3 inches in thickness. The sludge when shovelled off the filters contained 80 per cent. of moisture, and was accumulated for two or three weeks in that state without being at all offensive, until a sufficient quantity had been prepared for Milburn's machine, which was necessarily worked intermittently. The sludge from Campbell's process appears remarkably adapted for drying by filtration, a circumstance due to the absence of clay in the precipitants employed, to the large proportion of chemicals compared with the sludge, and to their porous condition. Its importance can hardly be overrated, inasmuch as it solves the difficulty of drying, which has been more troublesome than any other mechanical question. Experiments and analyses showed, moreover, that the value of the sludge was not affected by its filtration, whilst the quantity of moisture abstracted by it was at least one-half, even after the sludge had been brought to much greater consistency by draining off the water as it collected upon the surface.

The experiments were made on sewage collected in dry weather only. The results obtained did not always equal the one above referred to at Tottenham, for although the quantity of sewage in dry weather at the Model Works flowed with tolerable uniformity, the quality varied considerably and at short intervals, so that there was also great variety in the results. This variation in

quality was an advantage in experimenting, and would have been valuable if the sewage had at any time been rich.

The value of the manure was much affected by the presence of sand, which always formed 28 to 36 per cent. of the total weight, as against 20 per cent. or less at Tottenham. Such a proportion of sand may have been present in the whole of the sewage, and may have been consequent upon its passing through drains laid with steep gradients through the gravel of Clapham Common; but it was no doubt partly due to the difficulty of getting a fair sample of sewage from a sewer in which the suction pipe was necessarily placed close to the bottom, where it drew more than a due proportion of the heavier matters in suspension. The effect of the sand, as it increases the bulk, does not diminish the gross value of the manure obtained, but it reduces the value per ton and renders it less saleable.

In comparing the experiments, the cost of the superphosphate has been taken at £5 per ton, and the lime at 15*s.* per ton, those being the prices at which they could then be purchased, and higher than the prices in the Tottenham experiment. The manure was valued on the analyses of the chemists who reported upon it, taking ammonia as worth 18*s.* per unit, precipitated phosphates at 3*s.* 3*d.* per unit, and allowing nothing for the insoluble phosphates or organic matter.

On these bases, the best result at Wandsworth Road showed

	£	s.	d.
that the cost of chemicals per ton of manure was .	£2	13	4
Add other expenses as before, from Crossness . .	1	8	10
Total cost per ton	£4	2	2

And the value of the manure corrected to contain 18 per cent. of sand and 10 per cent. of moisture was £4 7*s.* 2*d.* per ton, thus showing a margin of 5*s.* per ton after payment of expenses. The worst result showed that the manure was worth about £3 per ton, or sufficient to pay the cost of the chemicals and leave a margin. Therefore it would appear that Campbell's process may be used for treating sewage equal to that of Tottenham, so as to repay the expenses of manufacture at least, and for sewage equal to the weakest at Wandsworth Road so as to repay the cost of the chemicals, and leave the expense of labour and drying (found at Crossness to be, as before stated, £1 8*s.* 10*d.* per ton) to be borne by the public. In either case the resultant manure, which contains from 13 to 21 per cent. of precipitated phosphate of lime from bone ash, in addition to the organic matter and ammonia usually obtained by precipitation processes, would probably compete better with

other manures in the market than those sewage manures which consist in great part of precipitants having no manurial value.

In confirmation of the above results particulars are given in the Appendix of experiments, both at Tottenham and at Wandsworth Road, in which the cost of chemicals and the value of the manure are reduced to the same standard for comparison. There are also added some analyses of the effluent water produced by Campbell's process at Wandsworth Road, and some information upon the comparative value of artificial manures.

III. Description of some of the Works erected for the Utilisation of the Sewage of Tottenham, by Whitthread's Process, and the Result.

Whitthread's process was brought out in 1872. It is described, in the Report of the Sewage Committee of the British Association of that year, as consisting in the addition of a mixture of dicalcic and monocalcic phosphate (the latter being added as commercial superphosphate), and then afterwards a little milk of lime. Mr. Hope, V.C., at the Social Science Congress, in the same year (1872), said of it:

"As yet the process has only been tried experimentally; it has not been thoroughly investigated, nor, in all probability, perfected, yet the result so far is remarkable and encouraging, because, although of course it cannot extract the ammonia in solution, it does remove altogether the other forms of organic nitrogen in solution. It therefore, to some extent, purifies the sewage; while not only is there a greater value in the matters removed by it from the sewage, than in those removed by any other process, but the material added is in itself a valuable manure."

Mr. Hope's opinion was formed on an experiment made on his Romford farm. The process was afterwards tried on a working scale at Luton and at Enfield, early in 1874; and in the latter part of the same year the proprietors formed a small private company for the purpose of working an agreement with the Local Board of Tottenham for the treatment of the sewage of that district.

The works then existing were transferred to the company, and the requisite additions were made to them. These were not of much interest for the purpose of this Paper, except in reference to the means adopted for mixing the chemicals with the sewage by a 'salmon ladder' mixer, and for drying the sludge. The sewage was pumped up into the precipitating tanks at the rate of about 1¼ million gallons per day, and a 'salmon ladder' mixer after the pattern of that used at Wandsworth Road was placed between the

pump and the tanks, through which the sewage flowed by gravitation at a velocity sufficient to prevent the subsidence of the chemicals, and with a disturbance enough to incorporate them thoroughly. This 'salmon ladder' (Plate 6) was 77 feet long by 6 feet wide and 2 feet 6 inches deep, and was fitted with groynes, 3 feet apart, projecting from each side alternately. It was raised 2 feet 9 inches at the inlet of the sewage, and had an inclination of 1 in 28. The phosphate was added to the sewage at the top of the ladder, and the lime at any suitable point in its length. Although the ladder increased the lift of sewage by nearly 2 feet, no objection was made to it. It was worked regularly from the time it was completed, and gave general satisfaction as a simple and effective means of insuring the admixture of the chemicals without machinery and its attendant cost and risk of failure.

To dry the sludge it was at first determined to use Needham and Kite's presses, and to reduce it to a solid state containing 50 per cent. of moisture; contrary to the advice of the Author, the presses and pumps to supply them were erected at considerable outlay. The sludge choked the pipes and pumps, and the labour and cost of the cloths for the presses were such that after a fair trial they were abandoned. Experiments with presses used in pressing beetroot in France, and others, also failed. It was then resolved to use the sludge filters, which had been successful in solidifying the sludge by Campbell's process at Wandsworth Road, and which small trials showed were applicable also to the sludge of Whitthread's process on account of its similar permeability. The filters were constructed in the cheapest possible manner, by forming the ground and draining its surface with agricultural drain pipes, surrounding the whole with a small earthen bank 2 feet high, and dividing the area into convenient compartments. The space was then filled with screened ashes, which were obtained gratis from the Local Board, to a minimum depth of 1 foot, and the sludge was run upon the top to a depth of about 12 inches. These filters were never constructed of sufficient extent, nor were they roofed over, on account of the financial difficulties which the company encountered; but their working was quite satisfactory in fair weather, and enough experience was gained to show, that a total area of about 18,000 square feet, which would have cost £1,000 when roofed, would have sufficed to solidify the whole of the sludge as fast as it was precipitated, and would have reduced it so as to contain from 65 to 75 per cent. of moisture.

For the treatment and complete drying of the solidified sludge two of Milburn's drying machines, with beds 30 feet by 6 feet, were

erected, and were in successful operation for several months. They would each turn out about 2 tons of marketable manure in twenty-four hours when fed with suitable sludge, with a consumption of coal in the furnaces equal to 1 lb. of coal for the evaporation of 5 lbs. of water, and they each required $1\frac{1}{2}$ HP. to drive them.

It was found that the steam from the chimneys of these machines had an unpleasant odour, which required to be dealt with by burning or washing, but this improvement was not effected. It is to be regretted that the works were stopped, because experience established the feasibility of the process, its precise cost, the saleable quality of the manure produced, and apparently the certainty of its ultimate success. The result of several months' working was:—

Taking the sewage treated at $1\frac{1}{4}$ million gallons per day, the dose of dry chemicals used was 2 lbs. per 1,000 gallons.

The cost of the chemicals was £3 17*s.* 6*d.* per ton.

The cost of the manure per ton, dried, bagged, and loaded for sale, was—

	£.	*s.*	*d.*
Chemicals	1	14	2
Coals for drying	0	14	0
Labour	1	0	7
Actual cost of manure per ton . .	£3	8	9

This was the cost with insufficient appliances, and there is no doubt that it could have been reduced to £3 per ton if the works had been complete.

Compared with Crossness:—

	£.	*s.*	*d.*
Chemicals	1	14	2
Other expenses, as at Crossness	1	8	10
Total cost per ton	£3	3	0

The works were favourable for testing Milburn's machines, because no coals were used for other purposes. The actual cost of fuel was 14*s.* per ton of dried manure, which would have been reduced to about 10*s.* per ton if the sludge filters had been of sufficient area for the treatment of all the sludge. The cost of labour in drying was 15*s.* per ton, but was capable of reduction to 9*s.* per ton, making the total cost of drying 29*s.* per ton, but capable of reduction to 19*s.* It was also shown that there ought to be no loss of ammonia in Milburn's machines, with proper management and care.

The quantity of sludge produced was equal to about 32 tons of manure per week. It contained about 2 per cent. of ammonia, and 8 per cent. of phosphoric acid in precipitated phosphates, equal to 17 per cent. of tricalcic phosphate; which, taking ammonia at 18*s.* per unit, as before, and tricalcic phosphate at 2*s.* 6*d.* per unit, would give a value of £3 18*s.* 6*d.* per ton, exclusive of organic matter, about 30 units, and 5 units of potash, estimated to be worth another 5*s.* per ton. The value of the phosphate is believed to be higher, but even at this low figure the manure would pay the expense of manufacture and leave a margin. It appeared to meet with a ready sale, for it left the works as soon as it was made, and it was reported to have been bought largely in Holland and in Belgium, both for present and future delivery.

The Author believes that the effluent water bore out the favourable opinion of Mr. Hope, and of the eminent chemists who reported upon it. It was shown to be satisfactory by a letter from the Home Secretary to the Lee Conservancy Board, in which reference was made to the official inquiry of Lieutenant-Colonel Cox at Tottenham, on the 25th of May, 1875, when the conclusion was arrived at that the Tottenham Board had used the best known practical means of dealing with the sewage of the district.

It is unfortunate that the company was compelled, by financial difficulties, to hand over the works to the Local Board, and that, partly owing to the doubt entertained as to the power of a local board to trade in the manufacture of manure, the Whitthread process has been for the present abandoned.

IV.—Conclusions.

However difficult, and even impossible, it may at present appear, there can be no doubt that any treatment of sewage which falls short of its profitable application in agriculture fails to solve the "sewage question." Precipitation is now generally believed to be unable to effect such a solution; yet it will hardly be disputed that it is capable of defecating sewage sufficiently to render it innocuous for discharge into the tideways of rivers, and capable also of clarifying it so as to increase the facility of dealing with it by filtration through land. The difficulty is to make the operation pay. This was abundantly shown by the Native Guano Company, when they proved at Crossness that their "extremely good effluent" cost £5 16*s.* 4*d.* per ton of the manure manufactured. Their experiment demonstrated that it was the bulk and consequent cost of the chemicals which caused the failure, and that the other

expenses of their process, even with imperfect means of drying, were only about £1 10*s.* per ton, which amount was approximately the comparative cost also of Whitthread's process at Tottenham, where the quantity of chemicals used was much less. From what has been said it will be safe to conclude that the cost of a precipitation process, apart from chemicals, is constant in relation to the manure manufactured, and is about 30*s.* per ton of manure.

But if one process makes more manure than another from a given quantity of sewage, the cost of treating that sewage will be increased. Similarly, if one process makes more manure than another from the same sewage, the increase will be due to the greater bulk of the chemicals employed, and consequently the value of the manure obtained from the sewage will be proportionably enfeebled, unless the chemicals are of at least the same value as the matters in suspension in the sewage, or unless they arrest the manurial matters in solution. It follows that the cheapest process in first cost, and apart from the value of the manure, will be that which requires the smallest quantity of chemicals; and that the least possible working expense will be incurred when the chemicals cost nothing, and when they have no solidity, but are added to the sewage in the form of aqueous solutions or gases. The minimum cost of a dried portable manure would in that case be about 30*s.* per ton, or £6 8*s.* 7*d.* per million gallons of sewage, containing 70 grains of solid matter per gallon, capable of extraction.

The following tabulated statement of results already given shows the influence of the chemicals upon the cost of treating the sewage, the other expenses being the same in each case.

The sixth column shows the comparative outlay on each process.

Process.	Place.	Dose, per 1,000 Gallons.	Cost of Manure per Ton.	Actual Cost of treatment per 1,000,000 Gallons.	Ditto, reduced to Standard Sewage of 70 Grains per Gallon.	Quantity of Manure per 1,000,000 Gallons of Standard Sewage.
		lbs.	£. s. d.	£. s. d.	£. s. d.	Tons.
A B C . .	Crossness .	31·80	5 16 4	70 15 7	67 4 9	11·56
A B C . .	Leamington	1·86	1 17 1	15 18 0	9 16 2	5·29
Campbell .	Tottenham.	9·76	4 0 9	25 0 9	35 12 2	8·82
Whitthread.	Ditto . .	2·00	3 3 0	10 12 6	16 17 0	5·35
Assumed minimum	..	nil	1 8 10	..	6 8 7	4·46

The minimum cost of dry manure being about £1 8*s.* 10*d.* per ton, or £6 8*s.* 7*d.* per million gallons of sewage of the standard strength of 70 grains per gallon (equal to £2,350 per annum, or thereabouts, for a population of thirty thousand persons), two alternatives are open—to remove and not dry the sludge, and to recover the outlay by the sale of the dry manure. In the first case, if the cost of drying is saved, the expense of treating the sewage will be about one-third, or £2 2*s.* 10*d.* per million gallons of 70 grains per gallon, provided that the sludge can be removed free of charge. This will be equivalent to £780 per annum on a population of thirty thousand, or 6¼*d.* per head; and economy in working expenses, of the precipitation of such sewage, cannot be carried further than this. It may be considered as the limit of "cheap precipitation."

For the recovery of the outlay, it is obvious that sewage manure can have no greater value than that which it derives from the sewage. The question is, what is that value? The Native Guano Company fixed it arbitrarily at £3 10*s.* per ton, and actually made a market at Leamington at that price for manure which derived much of its bulk from the sewage of that place; and there is evidence of equivalent results, though the same manure was valued by the Rivers' Pollution Commissioners at £1 12*s.* per ton by analysis. But it has been already shown that a value only of £1 10*s.* per ton will cover the cost of the manure if the chemicals cost nothing, and the ammonia alone obtained from most sewage that is worth treating by precipitation will produce that amount. In short, the success of precipitation depends on neutralising the cost of the chemicals employed, or, in other words, upon the admixture of precipitants which have a manurial value, and upon the eventual recovery of that value in the dry manure.

Such a problem would be easy of solution were it not for some practical considerations, of which by far the most important is the capital required, not only for the initiation of a process which will perhaps necessarily be an expensive one, but for its continuance in full operation during the seasons when manure is less saleable, and until the demand becomes equal to the supply.

It is not surprising that local boards shrink from the responsibility of such a speculation, even though, under certain conditions, and in good hands, success might be assured; nor can they be blamed for having recourse to the alternative of seeking to reduce the cost of the chemicals to the lowest point by buying the cheapest, and employing the smallest quantity of them which will suffice to appease the River Conservancy Boards. Possibly private

enterprise, which has done so much for this country, may again take the matter in hand, and, profiting by the experience of the past, may bring it to a successful issue. Meanwhile, precipitation is not in the hopeless condition which it is popularly supposed to be, and public bodies will do well to pause before they commit themselves to engagements to defray the entire expense of any process whatever. That which they should have done, and ought still to do, is to pay the minimum cost of £2 2*s.* 10*d.*, or thereabouts, per million gallons of sewage, and to require the owners of precipitation processes to pay the cost of their own chemicals, and of the conversion of the sludge into a dry manure. Such a course would reduce the public expense to the lowest point at present possible. It would, moreover, encourage private enterprise, and force the owners of processes to recover the value of the chemicals from the manufactured product, and would thus lead to a rapid solution of the "sewage problem," so far as that problem is capable of solution upon the principle of precipitation.

The Paper is accompanied by a series of diagrams, from which Plate 6 has been compiled.

[APPEND-

APPENDIX.

PARTICULARS OF EXPERIMENTS WITH CAMPBELL'S PROCESS,

Supplied by the Secretary of Campbell's Patent Manure and Sewage Company, Limited.

1st Experiment, 16th of July, 1872, at Tottenham, treating 3,500,000 gallons of Raw Sewage.

Chemicals employed.

	£.	s.	d.
6½ tons bone ash, at £6 10s. =	42	5	0
4¾ „ sulphuric acid, at £4 10s. =	21	7	0
4 „ lime, at 12s. =	2	8	0
15¼ tons.	£66	0	0

Dry Manure obtained.

		£.	s.	d.
21 tons (24 tons in reality).				
Precipitated phosphate,	23·14 per cent., at 3s. 3d.	3	15	6
Insoluble „	3·80			
Ammonia	1·45, at 20s.	1	9	0
Sand	16·37			
Value of manure per ton is		£5	4	6

10,000,000 gallons treated on above basis show the following results:—

Chemicals required.

	£.	s.	d.
43 tons 11 cwt., costing	188	9	0

Manure obtained.

	£.	s.	d.
60 tons, at per ton £5 4s. 6d.	313	10	0
Deduct cost of chemicals	188	9	0
Left for working expenses	£125	1	0

2nd Experiment, 10th of December, 1873, at Wandsworth Road, treating 5,900 gallons of Raw Sewage.

Chemicals employed.

	£.	s.	d.
56 lbs. superphosphate.			
16 „ dry lime.			
Total 72 lbs. chemicals, costing per ton	4	2	0

Dry Manure obtained, 112 *lbs.*

		£.	s.	d.
Precipitated phosphate,	21·66, at 3s. 3d.	3	10	5
Insoluble „	1·00			
Ammonia	0·935, at 20s.	0	18	7
Sand	28·60			
		£4	9	0

10,000,000 gallons treated on above basis show the following results:—

Chemicals required.

	£.	s.	d.
54 tons 10 cwt., at per ton £4 2s.	223	9	0

Manure obtained.

	£.	s.	d.
84 tons 15 cwt., at per ton £4 9s.	377	3	0
Deduct cost of chemicals	223	9	0
Left for working expenses . .	£153	14	0

Chemicals cost £2 12s. 9d. per ton of manure.

3rd Experiment, 10th of April, 1874, at Wandsworth Road, treating 3,358 gallons of Raw Sewage.

Chemicals employed.

32 lbs. superphosphate.
9¾ „ dry lime.

	£.	s.	d.
Total 41¾ lbs. chemicals, costing per ton	4	2	0

Dry Manure obtained, 56 *lbs.*

		£.	s.	d.
Precipitated phosphate,	21·87 per cent., at 3s. 3d. .	3	11	1
Ammonia	1·31 „ at 20s. .	1	6	3
Sand	17·30			
	Value of manure per ton	£4	17	4

10,000,000 gallons treated on above basis show the following results:—

Chemicals required.

	£.	s.	d.
55 tons 9 cwt., at per ton £4 2s.	227	7	0

Manure obtained.

	£.	s.	d.
74 tons 13 cwt., at per ton £4 17s. 4d. . . .	363	6	0
Deduct cost of chemicals	227	7	0
Left for working expenses . .	£135	19	0

Chemicals cost £3 0s. 10d. per ton of manure.

4th EXPERIMENT, 12th of March, 1875, at WANDSWORTH ROAD, treating 33,724 gallons of Raw Sewage.

Chemicals employed.

36 lbs. superphosphate.
11 „ dry lime.

	£.	s.	d.
Total 47 lbs. chemicals, costing per ton	4	2	0

Dry Manure obtained, 80 *lbs.* 8 *oz.*

	£.	s.	d.
Precipitated phosphate, 15·87, at 3*s.* 3*d.*	2	11	7
Insoluble „ 3·0			
Ammonia . . . . 1·17, at 20*s.*	1	3	5
Sand. . . . . . . 36·4			
Value of manure per ton	£3	15	0

10,000,000 gallons treated on above basis show the following results:—

Chemicals required.

	£.	s.	d.
56 tons 7 cwt., at per ton £4 2*s.*	231	0	0

Manure obtained.

96 tons 10 cwt., at per ton £3 15*s.*.	361	17	6
Deduct cost of chemicals	231	0	0
Left for working expenses . . .	£130	17	6

Chemicals cost £2 7*s.* 10*d.* per ton of manure.

MANURE PRODUCED from SEWAGE by TREATMENT with CAMPBELL'S PROCESS.

—	Experiment at Tottenham Works, July 16, 1872.		Experiment at Wandsworth Works, Dec. 10, 1873.	Experiment at Wandsworth Works, Apr. 10, 1874.	Experiment at Wandsworth Works, Mar. 12, 1875.	Total.	Average.
	Per cent.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Containing precipitated phosphates	23·14		21·66	21·87	15·87	82·54	20·63
" ammonia	1·45		0·935	1·31	1·17	4·865	1·216
	s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Market value of phosphates per unit	3 3	3 15 6	3 10 5	3 11 1	2 11 7	13 8 7	3 7 1
" " ammonia "	20 0	1 9 0	0 18 7	1 6 3	1 3 5	4 17 3	1 4 4
Total	..	5 4 6	4 9 0	4 17 4	3 15 0	18 5 10	4 11 5

ANALYSIS of EFFLUENT WATERS PRODUCED by TREATING SEWAGE with CAMPBELL'S PROCESS.

Experiment	Nov. 22, 1873.	Jan. 13, 1874.	April 10, 1874.	March 12, 1875.
	Per cent.	Per cent.	Per cent.	Per cent.
Mineral matter in solution	41·76	35·52	38·72	46·40
Organic " "	5·92	15·04	13·44	10·56
Total solid contents per gallon, in grains	47·68	50·56	52·16	56·96
Free ammonia	2·952	4·02	5·03	4·34
Organic nitrogen	0·217	0·3488	0·2405	0·27
Mineral matter in suspension	None	None	None	None
Organic " "	"	"	"	"

TABLE SHOWING the PRICES CHARGED by the LEADING MANURE MANUFACTURERS and the GUARANTEED ANALYSES of such MANURES.

	Soluble Phosphates.	Ammonia.	Price per Ton. £. s. d.
1. E. Packard and Co., Ipswich	23·85	0·97	7 10 0
2. J. B. Lawes and Co. (Limited), London . . .	26·00	—	5 5 0
3. Odam, London	16·00	1·50	5 10 0
4. C. Tennant and Co., Carnoustie	26·72	1·23	7 10 0
5. " " "	25·00	—	6 0 0
6. Morris and Griffin, Wolverhampton	20·00 (8 to 10 insoluble)	—	7 0 0
7. Langdale's Chemical Co., Newcastle-on-Tyne . .	28·00	—	6 0 0
8. " " " .	25·00	1·25	7 10 0
9. " " "	14·00 (20 insoluble)	1·28	8 10 0
Nine manures, containing .	204·57	6·23	60 15 0
The average will be .	22·73	0·69	6 15 0

Valued at the same rate as Campbell's manure, viz., 3*s*. 3*d*. per unit of phosphates, and 20*s*. per unit of ammonia, the value of the average manure would be £4 7*s*. 8*d*.

[Mr. RAWSON.

Mr. RAWSON, the Managing Director of the Native Guano Company, or A B C process, said he had come as an invited guest to hear and learn, without any intention of speaking. But he could not allow a moment to pass without answering the attack on the A B C process made by Mr. Shelford. He had been exceedingly surprised to listen to such remarks, which came with bad grace from a gentleman who had been the Engineer at the Crossness works. If disposed to retaliate, or to give an excuse for some of the extra cost occurring there, he might do so by showing that it was not the chemical part of the process that had been entirely at fault, but that much might be attributed to the engineering department. He did not think the Author should have made use of information obtained as Engineer to the Company to attack the process in so public a manner. No doubt, at Crossness they were wanting in experience, and jumped at conclusions too quickly. They believed thoroughly in the process, but had brought it too early to a crucial test. They went to Crossness for a three months' trial. Unfortunately they had been misled as to the object of the Metropolitan Board of Works, by being required to work under the supervision of the Chemist of the Board, Mr. Keates, who drew samples every day. Either he or his son was on the spot almost daily. The Company believed, therefore, that the inquiry would turn on the sanitary results; and the consequence had been that their attention was devoted almost entirely to the chemical part of the process. Mr. Keates, in his official report, stated that the channel through which the effluent water passed was never cleaned during the three months, and did not show the slightest trace of sewage fungus. This would prove the degree of purity of the effluent water. They then asked to be allowed three months' further trial to show the commercial part of the process, but they were ordered off the premises, and it cost them £500 to remove the works. It was a great surprise to some of the Thames Conservators to find they were sent away, for they were at all events cleaning a portion of the sewage of London to the great satisfaction of the Conservancy. That, however, was in the infancy of the process; and it was of little interest to the Institution to hear what had been done in 1872. The question was what was being done in 1876; and the members would no doubt be glad to have the latest official report on the working of the A B C process on the 29th of February last, by the Sewage Committee of the Leeds Corporation:—

"Town Hall, Leeds, 29th Feb., 1876.

"The Utilisation of Sewage Committee of the Corporation of

Leeds having now had, with intervals, more than three years' experience of the working of the system of purification of sewage by the process of the Native Guano Company, hereby express themselves as well satisfied with the results obtained at the works at Knostrop (especially with the effluent) as compared with the result of any other system which we have tried. The sewage of Leeds, as is well known, is very difficult to treat on account of the numerous dyes and waste products which are mixed with the ordinary domestic sewage; the daily flow in dry weather is about thirteen millions of gallons; since the new works have been completed this quantity has been purified at an average cost of about £1 per hour for chemicals, or £1 17*s.* per million gallons; but, with a new description of alum, now about to be tried, and with charcoal prepared from the sludge, we confidently expect to be able to reduce the cost. On two recent occasions, samples of the effluent water were taken every few hours for a fortnight (the process being worked continuously day and night). These samples were mixed together and analysed by Dr. Letheby, whose reports show that the water is fit to be turned into any river.

"The sludge has not yet been converted by us into a saleable manure; but four drying cylinders are just ready for use, and will at once be set to work. It remains to be proved whether the sale of the manure will pay for the expenses incurred in the manufacture, but from replies received from many farmers and gardeners who have used some manufactured at the experimental works, it appears to be well suited for grass land, garden produce, plants, and flowers.

"Up to the present time we know of no system more likely to answer our requirements; and if the manure is saleable at £1 per ton, it will pay expenses. Our own trial on grass land at Knostrop shows the value to be £3 10*s.* per ton as compared with Peruvian guano at £15.

"Signed on behalf of the Committee,

"George Tatham, *Chairman.*"

The sewage of Leeds was of a most extraordinary character, changing at all hours of the day from green to blue, and from blue to black; yet the effluent water was as bright—he did not say as pure—as a mountain stream, and was fit to go into any river. According to Mr. Tatham's report, if the manure could be sold at £1 a ton it would pay all expenses. The company had sold more than 4,700 tons of native guano at an average price of nearly £3 10*s.* a ton, and the farmers who had begun with 5 tons or 10 tons, came to Leamington for 50 tons, 100 tons, and even 200 tons. He did not

attempt to explain why the manure, which he admitted did not yield on analysis high results according to the ideas of agricultural chemists, was worth so much money; but that it produced good crops was the experience of hundreds of farmers whose testimonials had been published, and whose names and addresses were given, so that their reports could be easily verified.

Mr. Grindle complained that neither the Lime process nor the Phosphate sewage process had been mentioned. The latter process, he believed, was about the only one that dealt with the sewage of towns entirely, and sold it at a profit. It had been in operation for twenty months at Hertford, and had given entire satisfaction. Twelve or fifteen months ago the Lee Conservators, on receiving a complaint from below Hertford, had an analysis made; and Mr. Keates stated that the effluent water was such as might be allowed to run into any river.

Dr. Voelcker said that the disposal of the excreta of towns was indeed a gigantic undertaking, and it was far too wide a subject to be treated in the time at his command. The difficulties in the way of removing the sewage of towns were admitted on all hands, but they were greatly increased when the excreta were plunged in water instead of having them pure and simple. The cheapest mode of dealing with town refuse was to carry it as produced direct to the land—a method adopted in Flanders and in some parts of Germany. He wished to disabuse the minds of some sanguine persons of the idea (which he believed was gradually losing ground) that money could be made by human excrements. He could not share the opinion expressed by Mr. Redgrave, although he believed that from urine valuable products, such as ammonia salts, might be extracted, leaving a slight profit to the manufacturer; but against this should be placed the loss which was experienced in the manufacture of the solid excreta into dry and portable manures. He knew of no process, nor did he believe that any such existed, by which these could be profitably converted into portable manures. Some years ago he travelled all over Belgium with a view of getting special information from the town authorities, who had the disposal of sewage matters entirely in their own hands; and he found that there was not a single place, though the excreta were collected most carefully and undiluted with any slops, where more than 1 franc per head was realised, and in most places the town authorities had to pay for the collection and removal to the country. Some years ago, also, a commission had been appointed by the Prussian Government, and it ascertained that there was not a single town in Germany in which a profitable return was made for the

disposal of the sewage, and in most places the authorities had to pay for the removal. If this was the case with the excreta unmixed with ashes or slops, it was obvious that the expense must be vastly increased when they were diluted with an immense quantity of water. He could not understand how, by Mr. Campbell's process, in the treatment of 10,000,000 gallons of sewage, the sale of the manure produced could leave for working expenses £125. Before criticising the figures a little more closely, he wished to point out two practical mistakes that had been made. The precipitated phosphates were set down at 3*s.* 3*d.*; that was the price of soluble phosphate, but the value of precipitated phosphates was 1*s.* less than of phosphates actually soluble in water, which of course would make a considerable difference in the final result. Then, again, ammonia was set down at 20*s.* In sulphate of ammonia, however, ammonia could be bought for 16*s.* per unit per cent. But that was not all: the sewage precipitated, whether by the superphosphate process, or by Messrs. Forbes and Price's process, or any other, did not contain actual ammonia, but organic matters yielding ammonia very gradually. The precipitation did not remove any ready-formed ammonia. Only the suspended organic matters which contained nitrogen were collected, and that nitrogen was put down in the estimates as ammonia. In that shape the commercial value of the ammonia was very different from its value in the shape of ammoniacal salts. Even 15*s.* per unit would be a high estimate; and that again would materially reduce the value of the manure produced. So that instead of £5 5*s.*, a more correct estimate perhaps would be £4 4*s.* per ton. Then there was another matter which he could not quite understand from the figures given. Assuming the figures to be correct, and taking the ammonia at 20*s.*, the manure produced from 10,000,000 gallons of sewage was 60 tons; the value of the ammonia in 1 ton was given at £1 9*s.*, bringing up the value of the ammonia in 60 tons of manure to £87. It was well known that by using a precipitating agent like superphosphate and lime, not a particle more of phosphoric acid was produced from the sewage than was actually thrown into it. Indeed, he did not believe that the full quantity thrown in could be got out again. The total benefit of precipitation arose from the removal of the suspended organic matter containing nitrogen; or, to express it briefly, its ultimate utilisation as ammonia, which was worth, according to the statement, £87. The cost of the superphosphate required was put at £188 9*s.*; adding to that the value of the ammonia, the total value of the manure that ought to be produced was £275 9*s.* But in the estimate the value

was given at £313 10*s.*, showing a difference of £38 1*s.* He did not understand how the value could be possibly increased, indeed the opposite was the case. As he had already stated, the value of soluble phosphate was reduced 1*s.* for each per cent. in becoming precipitated. The manure, according to the statement, contained 23 per cent. of precipitated phosphates, which would give a reduction of 23*s.* per ton; or for the 60 tons of manure produced the reduction in value would be £63. He had taken the original value of the chemicals themselves, without making any allowance for the fact that they were immersed in water, and then had to be dried again. Allowing £87 as the value of the nitrogenous matter precipitated from 10,000,000 gallons of sewage, and deducting from that sum £63 for reduction in the value of the soluble phosphates in becoming precipitated, there remained for working expenses only £24, and not £125 1*s.* But the value of the nitrogenous sewage matter, calculated on the basis of 15*s.* per unit ammonia (and even at that price they would be dear), was only £65 5*s.*; consequently there remained a margin of only £2 5*s.* for working expenses. Mr. Shelford stated that the cost of the precipitation process, apart from the chemicals, was about 30*s.* per ton; therefore 60 tons would entail an expense of £90. If the town authorities gave a subsidy of only £2 2*s.* 10*d.*, or say £2 3*s.* for a million gallons of sewage, that would amount to £21 10*s.*, and deducting that from the cost of production, £90, there would remain a deficit of £68 10*s.* for every 60 tons of manure produced, or the manufacture of every ton of manure would entail a loss of £1 2*s.* 10*d.* It was no wonder, therefore, that speculations in sewage companies and precipitation processes of every kind could not possibly pay, unless the town authorities made up their minds to put their hands deeply into their pockets.

Mr. C. Walford remarked that he had been struck, as an amateur, by the absence of any mention of Dr. Anderson's process. It had been stated that the difficulty of precipitation processes was the cost of the chemicals. The essential ingredient of Dr. Anderson's process was shale, which he obtained at a small cost, so that difficulty had been overcome. He hoped the method would have a fair trial, and believed it would hold its own against any that had been mentioned.

Mr. E. Meyerstein said, Dr. Voelcker professed to point out two practical mistakes in the Appendix to Mr. Shelford's Paper, and one of them he tried to prove by giving the value of precipitated phosphates as only 2*s.* 3*d.* per unit, or 1*s.* less than that of soluble phosphates. The reason assigned for the less value of

precipitated phosphates was that they were not so assimilable or serviceable for plants. That might be Dr. Voelcker's opinion, but it was not shared by other chemists of standing and learning, and it was certainly at variance with the report sent by him to the Phosphate Sewage Company, which, after giving an analysis of a sample of the manure produced by the Phosphate Sewage Company's process stated, "The whole of the phosphoric acid, I may state, occurs in this manure in the shape of precipitated phosphate, a form, I need hardly say, in which the phosphates are readily available by plants. Being obtained by precipitation from their solution, the phosphates are present in the deposit in a very efficacious form."

A chemist of acknowledged authority in agricultural matters, Mr. Frederic A. Manning, reported about precipitated phosphates, "The manure, the analysis of which I append, is evidently a precipitated phosphate of lime, and is therefore in a finely divided state, and readily assimilable by plants, although not actually soluble in water. All soluble phosphates of lime, on mixing with the soil, are immediately converted into the insoluble or precipitated form; it follows, therefore, that the manure is but little inferior in agricultural value to the superphosphates of lime in the market of the same percentage composition. The cost of soluble phosphates to farmers is about 4*s.* per unit per ton. . . . . The value of precipitated phosphate, though less than that of soluble phosphate, is certainly higher than that of guano. I think, therefore, that 3*s.* 3*d.* per unit per ton is a fair valuation of precipitated phosphate."

The well-known analyst Mr. Alfred Sibson, wrote on the same subject, "Having issued a scale for the valuation of manures, I make it a rule not to give the money value of the manures I report upon. It will be seen, however, from the values I have given, viz., 3*s.* per unit for precipitated phosphates, and 20*s.* for ammonia, that a manure of the composition analysed by me will be of a fair market value."

Before compiling the tables in the Appendix to Mr. Shelford's Paper, he consulted several gentlemen capable of forming an opinion, and as their estimates of the value of precipitated phosphates varied from 3*s.* to 4*s.* per unit, for the purpose of being within the mark he adopted 3*s.* 3*d.* as the basis.

The next practical mistake Dr. Voelcker had pointed out was that ammonia according to his theory was worth not 20*s.*, but, in the state in which it existed in Campbell's manure, 15*s.* per unit. But how was it that in an analysis furnished by Dr. Voelcker to the Phosphate Sewage Company he gave the equivalent of the organic

matter in ammonia? He stated, "Organic matter and water of combination, 20·11. Containing nitrogen, 0·57—equal to ammonia, 0·69." How was it, if he valued precipitated phosphates at only 2*s.* 3*d.* and ammonia at 15*s.* per unit, that in the same report he wrote as follows: "The sample analysed by me contains an amount of precipitated phosphate which is equivalent to 62 per cent. of tribasic phosphate of lime, and an appreciable amount of nitrogenous organic matter capable of yielding 0·69 per cent. of ammonia. It possesses valuable fertilising properties, and, in my opinion, a sewage manure equal to the sample analysed by me will command a ready sale at £7 7*s.* per ton."[1]

It should be borne in mind that the phosphate contained in the manure produced by the Phosphate Sewage Company was not phosphate of lime, but phosphate of alumina, which was on all hands admitted to be next to worthless for agricultural purposes. Yet Dr. Voelcker reported not only that the manure containing no other fertilising matter than 0·69 per cent. of ammonia was worth £7 7*s.* per ton, but he added that it would command a ready sale at that price. Dr. Voelcker had had too much experience in issuing reports not to be careful in drawing up such documents; and since the estimated valuations in the Appendix were much below those put by Dr. Voelcker upon the constituents of the Phosphate Sewage Company's manure, he certainly ought not to impeach their correctness. The valuation of the various manures mentioned in the last table of the Appendix was on the same basis as that of Mr. Dugald Campbell's manure; the comparison drawn was therefore a fair, just, and correct one. Dr. Voelcker had said it was well known that, by using a precipitating agent like superphosphate of lime, not a particle more of phosphoric acid was produced from the sewage than was actually thrown into it, and he did not believe that the full quantity thrown in could be got out again. No attempt had been made to substantiate the assertion, nor had he even taken the trouble to witness any experiment in connection with that process, nor did he profess to have devoted much time to the study of sewage experiments. When speaking of sewage at a meeting of the Society of Arts, on the 6th of December, 1871, Dr. Voelcker, according to the report of the Society's "Journal," made the following statement: "His name had been mentioned in connection with the phosphate sewage process. He would mention that he had nowhere expressed any opinion upon the commercial bearing of this matter, but merely that the phosphate

[1] *Vide* "Chemical News," March 10th, 1871.

sewage process patented by Dr. Forbes so far purified the sewage, if carefully practised, that the water was admissible into a stream of running water."[1]

In conclusion, Mr. Meyerstein remarked, that the least costly was not always the cheapest mode of doing things. If the sewage of a town could be purified, without the aid of chemicals, at a cost of £1 8*s.* 10*d.* per ton of dry deposit—which he believed was the lowest estimate given in Mr. Shelford's Paper—that cost and the cost of removing the deposit would have to be borne entirely by the ratepayers; for, devoid of any fertilising constituents, the deposit could certainly not be sold. Farmers had learnt that it was cheaper to buy manure of a high percentage of fertilising ingredients than a low-priced article, for on the latter they had to pay so much more for carriage and for applying it to the land. Did it not stand to reason that if a saleable manure could be produced by the admixture of certain chemicals to sewage, even assuming that it did not leave a profit—which he maintained it did—it would relieve the ratepayers of a heavy burden?

He thought he had said enough to prove that the figures given in the Appendix were justified, and that Dr. Voelcker's strictures were certainly not merited.

General Scott believed that nearly all that could be said on the subject had been said; yet such discussions were important in educating the public up to the point of insisting that the knowledge possessed should be taken advantage of. During the last three or four years a great change had taken place in the views of town councils with reference to the disposal of sewage matter. They formerly believed that they had in sewage a material which was saleable at a profit, but they had now discovered not only that it was valueless, but that they must be at considerable expense in removing it. The first question he should ask, if consulted as to the best mode of getting rid of water-carried sewage, would be, "Are you near enough to the sea to get rid of it in that way?" In regard to "dry sewage" they were on somewhat different ground. He was not of Dr. Voelcker's opinion, that no benefit could be derived from turning it into a concentrated manure. Many would, no doubt, say that the dry-sewage system was entirely a mistake; but the fact could not be got rid of, that a large proportion of the manufacturing population of the country made use of cesspools, pails, or some other convenience of the kind. That being so, and many town councils refusing to adopt a water-carriage system, it

[1] *Vide* Journal of the Society of Arts, vol. xx., p. 69.

became the duty of engineers to endeavour, at all events, to reduce the expense of dealing with dry sewage. A few years ago the ordinary excreta of towns, mixed with ashes, realised in some cases *4s.* or *5s.* per ton; by degrees the manure was reduced to *1s.* and *1s. 6d.*, and then to *5d.*, and in many cases there was now a difficulty in getting rid of it. In many towns it was a common practice to "tip" it, and then build houses upon it. That certainly was an expensive method of dealing with it, for it was most costly to human life; and it would be better, even at a pecuniary loss, to turn the sewage into a concentrated manure. He believed that, by giving attention to the subject, much might be added to the comfort of the people and to the value of the produce. He had never used one of the pails introduced by Mr. Alderman Taylor (to whom the country was much indebted for the Rochdale system); but he had been given to understand that disagreeable consequences from splashing sometimes ensued. An obvious remedy would be to allow the liquid to run into another receptacle. Dr. Voelcker, while believing it to be useless to attempt to get any value out of the solids, said that some small advantage might be derived from manipulating the liquids. If the solids and liquids were allowed to mix and to be shaken up in the cartage, the subsequent separation was a difficult matter. It might not be possible, by any known method, to derive a money value from dry sewage, but every year it became more and more difficult to deal with it mixed, as it formerly was, with ashes; and the most economical plan would ultimately be to convert it into a concentrated manure. Besides, it was possible, though not probable, that the importation of foreign guano might be cut off through war, when it might be desirable to use home-made guano. He would not trouble the members with any details of the plan he had devised with a view of extracting ammonia from urine, but Mr. Redgrave had exhibited some bottles exemplifying the results of the process.

With reference to water-carried sewage, he quite concurred in the statement of Mr. Shelford, that in the precipitation of sewage the cheapest material should be used. He did not, however, think that bone phosphate was the cheapest, but nevertheless phosphoric acid might be employed under certain conditions with advantage. In some of the northern towns, for instance, where muriatic acid could be obtained at a cheap rate, and phosphates were also readily procurable, it was possible that by a judicious use of these materials some advantage might be gained, but he thought no such advantage could be obtained by precipitation, as recommended by Mr. Shelford. A material was employed in the process worth £5

or £6 a ton, and it was converted into a material worth only £3 or £4 a ton. He admitted that if it could be readily sold as manure for £3 or £4 a ton, it might answer well, because a certain amount of nitrogen could be obtained from sewage water; but the tendency of farmers was to buy higher classes of manures, and it would be impossible to dispose of large quantities of manures of this low value. The difficulties in the way of turning out a valuable manure, in the manner proposed by Mr. Shelford, arose from the foreign elements present in the sewage. There was a quantity of detritus in town sewage, and, owing to the large quantity of lime required to neutralise the acid of the precipitant, there was also mixed with the deposit a large quantity of carbonate of lime, which further degraded its value. In one of the first experiments made by the Phosphate Sewage Company, there was, according to an analysis by Dr. Voelcker, as much as 50 per cent. of carbonate of lime precipitated. It appeared to him that the solid matters should be allowed to subside first as far as they would, and be dealt with separately; then the lime should be added to the sewage water, to precipitate the carbonic acid; and, thirdly, to the limed effluent sewage-water should be added the solution of phosphate, each operation being conducted in a separate tank. In that way the phosphate of lime might be obtained separated from the carbonate of lime and the silicious matters. Practically, in that way he had been able to obtain in the third tank a manure worth about £7 a ton, because the phosphate of lime in the act of precipitation carried down a considerable quantity of nitrogen from the sewage water, which added considerably to its value. But such a plan was only practicable when both phosphates and acids were very cheap. With regard to the first deposit, consisting of silicious matters mixed with organic matter, they might be dealt with separately as an inferior class of manure; they would be small in quantity as compared with what they would be if mixed with the other precipitated matters, and it was easy to deodorise them by a small addition of lime. Even 2 or 3 per cent. of lime mixed with sludge was sufficient to deodorise it. The second deposit, consisting chiefly of carbonate of lime, could be calcined and be re-used. He had carried on the process of re-using as many as six times, and still found that the lime precipitated very well. Such a process of phosphate precipitation might be feasible in manufacturing towns in the North; but in other cases, where the ocean was not at hand to receive the sewage, he believed that the cheapest way of dealing with it would be by precipitating it first with lime only, and then, when the Legislature required that a further purification

should be carried out, the clarified sewage water could be passed through a small quantity of land, to filter and cleanse it thoroughly.

Mr. Alderman TAYLOR, of Rochdale, considered it disgraceful that a civilised community should be now discussing "How to do it," or rather, as he thought, "How not to do it." Town councils had been learning in the dear school of experience. Rochdale had been trying the pail and manufacturing system, but a clamour was raised by some persons who thought it a failure, and the committee consequently recommended that the manufacturing should be discontinued for twelve months. That was accordingly done, but the result was so disastrous that they were now going to revert to the former system. There really was no difficulty in the use of pails in Rochdale, so far as offensiveness was concerned. Last year the number of pails used was 4,741, this year 5,566, no compulsion whatever having been employed by the town council; it was a voluntary thing on the part of the owners, who had abandoned the old midden-closets, and in many instances water-closets. This showed that the pail system was appreciated by the inhabitants. He did not wish to be understood as recommending the dry system only. No one advocated more thoroughly than himself the process of irrigation; but he advocated with equal earnestness the keeping out of the sewers of all excreta and urine. Whenever the water-closet system was used, the value of all sewage was weakened to the extent of fully one-half, notwithstanding the admission of excreta and urine. In water-closet towns the quantity of water consumed per head was almost double, and the sewage was so greatly weakened that it became necessary to buy more land. The great difficulty was to get land at a fair market price. If landowners were not so intent upon levying blackmail upon towns, there would be no difficulty in dealing with the sewage question; and if other towns would profit by the example of Rochdale, and the valuable hints of General Scott, they would not only be able to collect and distribute the excreta and the sewage, but to do so with a profit. He did not agree with Mr. Redgrave that it was possible, by a modification of the midden-closet system, to effect a removal without offensiveness and injury to health. Offensiveness had nowhere been avoided except by the adoption of pails. He agreed as to the advantage of separating the liquid and solid matters, but not precisely in the manner pointed out. He also concurred in the suggestion that the removal of excreta and ashes should be carried on by the local authorities under stringent supervision. The town council of Rochdale had recently passed a resolution abolishing "tips." There would be extreme difficulty

in carrying out the resolution, but they were determined to do it; and he believed that the refuse of towns might, if properly used, be made profitable. They now utilised nearly all their refuse. The calculation had been made for the year just ended, showing that the cost to the town, when the manufacturing system was not adopted, was between £1,000 and £2,000 more than it was under that system. If they manufactured, and did not dispose of any of it, it was found to be cheaper than selling the matter in its crude state, for the carriage of the crude manure exceeded by some shillings per ton the amount received for it. On the other hand, of the manufactured manure, this year they had sold 2,140 tons, being an increase of 140 tons over the previous year. The amount received for the manure was £2,380, a tolerable income for a material said by some to be worthless. He believed that a much larger sum would ultimately be realised, and he hoped that, instead of the manure being worth £1, it would realise £2, £3, or even £4 per ton. They were able to use their refuse even to the finest ash. He did not like the idea to go abroad that the ashes should be thrown away. In all fine ash there was at least 6 per cent. of sulphuric acid, and a certain amount of phosphoric acid; so that it was not altogether worthless. It was far better so to use the material than to allow it to be thrown into "tips" and be built upon. It had been the custom to throw away refuse and build afterwards upon it. One local board, near Rochdale, gave £100 a year for a place of that kind, which would certainly be built upon within thirty years; and it was disgraceful that such a thing should be allowed. The report of the Rivers' Pollution Commissioners ought to convince every one that for manurial processes sewage irrigation was the only plan to be adopted. That was for sewage proper, but not for excreta. With regard to the remark of Mr. Redgrave, that the Goux system was the forerunner of the system adopted in Rochdale, he wished to observe that Rochdale was really the forerunner in the matter. In 1865 he himself wrote to the scavenging committee, detailing almost the very plan now practised. They tried the Goux system as it was patented, and it failed, and the advocates of that system then adopted the method employed at Rochdale, so far as collecting was concerned. He believed that Rochdale had got over many of the difficulties of former days, and that in a short time it would adopt irrigation, if only land could be obtained at a reasonable price. He hoped both systems would be carried out as he had suggested, so that waste might be avoided and a gain secured.

Mr. Melliss desired to bring under notice the process known

as Dr. Anderson's—the sulphate of alumina and lime process, which had been in operation during the last three years at Nuneaton, and during the last two years in Coventry. In the latter town every gallon of sewage was purified under the strict supervision of the officers of the Corporation. The town contained forty thousand inhabitants; the sewage was very foul, being mixed with manufacturing refuse from dye and varnish works; the number of water-closets was about five thousand. It was often supposed, in regard to purification by chemical precipitation, that the most difficult thing was to get a purified effluent water. That was no doubt true to some extent, but the greatest difficulty was how to get rid of the solid matter. This rendered the Lime, Campbell's, and some other processes impracticable. Birmingham had been held up in "The Times" as an example to be followed, but the process adopted there was a complete failure. In the first place, the effluent water was procured by treatment with lime, and lime-water, it was well known, would kill fish or any other animal life. In the next place, the Corporation did not know what to do with the deposit. They had 220 acres of land in which to bury it, but that could not last long. It appeared from Mr. Shelford's description of Mr. Campbell's process that, in dealing at Tottenham with 3½ million gallons of sewage, 15¼ tons of chemicals were used. The yield of dry manure was 22 tons, equal to 132 tons of sludge. According to that proportion, the quantity of chemicals required for such a town as Leeds would be 53 tons per day. Adding that to the sewage, there would be about 500 tons of sludge to dispose of daily. At Coventry 2¼ million gallons of sewage were treated daily; 15 cwt. only of solid chemicals were put in, and 4½ tons of dry manure were obtained, or 25 tons of sludge. At Birmingham 17½ million gallons were treated daily, 14 tons of lime were put in, yielding 400 tons of sludge, representing 66 tons of dry manure. It was obvious that the less solid matter put in, the easier it was to get rid of the sludge; and there could be no doubt that precipitation processes had hitherto been greatly hindered by this difficulty. It appeared from the Report of the Royal Commissioner on the purification of the Clyde,[1] that the solid matter or manure estimated to arise from the sewage of Glasgow amounted to between 400,000 and 500,000 tons annually; but, according to the experience at Coventry, the actual solid matter that ought to be produced was only 40,000 tons. Precipitation was said to be an expensive process, but it was not so when properly managed. The cost of purifying 2¼ million gallons of sewage

[1] *Vide* Report of Sir John Hawkshaw, p. xi.

a day at Coventry, reckoning no sale of manure, was 1*s.* 7*d.* per head per annum; the cost at Merthyr Tydvil was 1*s.* 8¾*d.*; at Leamington 1*s.* 6½*d.*; at Warwick 3*s.*; at Banbury 1*s.* 7*d.*; at Northampton 1*s.* 8¼*d.*; at Tunbridge Wells 5*s.* 3*d.*; at Norwich 3*s.* 6*d.*; at Croydon 2*s.* 1½*d.*; at Kendal 1*s.* 2¼*d.*; at Eton 5*s.* 1½*d.*; at Swindon New Town 3*s.* 7¾*d.* These amounts included the purchase and preparation of the land, and the main outfall sewer, when it was at a considerable distance.

Lieut.-Colonel Jones, V.C., was glad to find it stated that the dry system was chiefly applicable to places in which there were natural local impediments to the use of water as a carrier. As a sewage farmer he believed that water carriage, wherever it was applicable, was the best and most satisfactory method to adopt. But he was so far free from prejudice that, on the sewage farm which he cultivated, he used nothing but earth-closets for deodorising and getting rid of the fæcal matter produced on the premises. Under certain conditions, that was perhaps, in a sanitary point of view, the most satisfactory method of dealing with the subject. The most important of these conditions was the efficiency and the daily superintendence of the labour required in supplying earth and removing manure—a condition which it was difficult to attain on a large scale. There should also be plenty of store room under cover to protect the dry earth from the fluctuations of the weather, and to protect the manure during the interval between its appearance in the closets and its removal to be dug into the land. Under such circumstances, and where the necessary water for water-closets would have to be pumped from a deep well, there was good reason for adopting the dry-earth or ash-closet system. But, after all, there were the slops and kitchen refuse, and manufacturing liquids, to be removed from large towns; and if there were a properly constructed sewer to take that refuse away as quickly as possible, he saw no reason, in a sanitary point of view, why the fæcal matter should not go with it, because he maintained that it ought to be immediately removed, together with everything foul, to the outfall, and spread upon the land. That was not an occasion to enter into a discussion with regard to the utilisation of liquid sewage, but he hoped at the forthcoming Sewage Conference to be able to show that a sewage farm, conducted under reasonably fair conditions, even where the rent of land was £5 an acre, could be carried on at a satisfactory profit. With regard to the valuations of precipitates in the second Paper, reference was made solely to the standard of theoretical value. He always endeavoured to reconcile theory and practice; and when practical results did not follow, he was led to

believe that there was a mistake either in the theory or in the mode of its application. In the present circumstances he had no doubt that the mistake was in the application. The theoretical value of ammonia was pretty well established, but that standard was only applicable within certain limits, namely, with a percentage of from 10 to 15 per cent. of ammonia, which might be fairly compared. In regard to the comparison of manure with 1 or 2 per cent. of ammonia with manure containing 12 or 13 per cent., any wise farmer would prefer to buy the more expensive article, having the least bulk, because of the cost of carriage, and of spreading the manure upon the land. Even if the manure was delivered and spread upon his fields free of expense, he would prefer to have guano, because the texture of the soil might be spoiled by the additional carting required for the other.

Mr. HAVILAND said, as a Medical Officer of Health over a large area in Northamptonshire, he often found himself in a difficulty in regard to the disposal of sewage. In 1874 he had recommended the authorities to take into consideration the different modes adopted, and he had himself made a tour of inspection with that view. He visited Aldershot, where the Goux system was adopted, and Halifax, where it was first applied in the autumn of 1870, to see its results in the case of a large town. The Registrar-General had given him permission to investigate the mortuary returns in that town for the last six years, 1870–5, during which there was an average of 25 closets per thousand inhabitants. These returns included two trienniums, during the first of which (1870–2) the rate of mortality was increasing. From 1866 to 1871 it had increased rapidly: in 1869 it had risen to twenty-six per thousand, and in 1871 to thirty-one. In the first triennium there were no wards with a mortality above the average, only two wards with a mortality from all diseases below the average, and only three with a mortality from fevers below the average. That was at a time when the Goux system was only partially carried out, the number of closets being 14 per thousand. In the second triennium, when the number of closets was 37·6 per thousand (there being only two wards below the average), there were six wards out of the ten with a mortality from all diseases below the average, twenty-six to every thousand persons; and in regard to fever mortality, only two wards were above the average. If these results were not altogether to be attributed to the adoption of the Goux system, he could not help thinking that something should be attributed to the sanitary action which took place under that system. He had under his medical charge three hundred and

sixty-five towns and villages, and, from practical experience, he believed three things were essential—scavengering, the dry-sewage system, and a place to put it; a "muck-acre," from which to remove the manure to the land. So far as he had seen, the Goux system offered the greatest benefit, removing as it did many of the difficulties with which he had had to contend. He might mention that Halifax, from its hilly character and the difficulty of carting, was a troublesome place to deal with; and yet the results had been such as he had described.

Mr. ALFD. M. FOWLER said, in Salford seven systems were at work. With reference to the method carried out at Rochdale, it should be remembered that that town was on a tributary of the Irwell. He had had twenty-five years' experience in connection with the sewage of towns, and he knew that in Leeds, where he had been Engineer, the cost of collecting, with the box system, was 9*s.* 3½*d.* per ton in a ward of fifteen thousand inhabitants, where the depôt adjoined the river, so that there was no distance to cart the material. The amount received for it was not more than 1*s.* or 2*s.* a ton. The total cost for collecting in the ward was £1,800 a year, and the total cost in the borough was £21,000. Besides that, the liquid sewage was still on its way to the sewers. Tanks had been constructed, designed by himself, and it cost the authorities £15,000 a year for chemicals alone. That was a town under a Chancery injunction; and Rochdale would perhaps have the same thing by-and-by. He was now constructing a sewer in Salford, at a cost of about £100,000, to guard against the difficulties of the Court of Chancery, and the Corporation had purchased 40 acres of land for the same purpose. Was it likely, under such circumstances, that Rochdale would be allowed to pour its sewage into the Irwell? Certainly not. The theoretical value of manure had never yet been realised. In dealing with the sewage of a town, it was absolutely necessary to put down nearly 1*s.* in the pound for it; and it was simply fencing with the matter not to do so. It would cost 6*d.* in the pound to deal with the sewage properly, and the sooner the work was set about the better. Leeds was setting about it boldly. He did not know that they had sold their manure. They had advertised the use of the works in the principal papers in the country, and offered every facility for experimenting at the works. Several persons had tried experiments there, but without any useful result. A contract had been previously entered into with the A B C Company. That enthusiastic body set a fictitious value upon the manure; it therefore went to the ground, and the contract had been cancelled.

They again, however, sent for the company, believing it was the best thing to do. He had taken samples of the effluent from the sewage water, in which the fish thrived better than in the water supplied to the town. Where the tub system could not provide for the collecting of liquid sewage, it was far better and cheaper in the end to turn the refuse into the sewer. If all the excreta were kept out of the sewers, not an acre less irrigation land would be required, and not an inch less depth would be needed in the tanks. The refuse of bedrooms, liquid sewage, &c., should all go into the sewers. The country was alive to the question of the pollution of rivers, and it was absolutely necessary that the subject should be dealt with. He believed that Leeds would save £14,000 per year if all the refuse could be turned into the sewers at once. If it all went down to the outfall, it could be dealt with in the usual way by the A B C process. It had been proved by Professor Frankland that the water flowing from the tanks at Wrigley's works, having been taken from the river Roach, was actually purer than the best supply to London from the Thames. The universal supply of water-closets throughout the country was, he thought, the true solution of the sewage difficulty. In Salford he had designed a water-closet that utilised the whole of the refuse water from the house in passing the fæcal matter into the sewers, so that no town water supply was required. Fifty of them had been made, and they acted so satisfactorily that every engineer who had seen them approved them.

Mr. Alfred Smee considered the time had arrived when fixed principles should be adopted to determine how to deal with sewage. Two Papers were under discussion, one dealing with what might be termed the dry method, which would only be used when the wet process could not be adopted. Two difficulties in the dry-earth process had not been adverted to: one, the difficulty of supplying dry earth; the other, the extra cost which would be entailed on the community if the ashes of the house were used as a disinfectant. At present they were employed in brickmaking, and he was assured that the cost of houses would be sensibly increased if all the ashes were used as disinfectants, however admirably they might be adapted for that purpose. But in every large town the common verdict of mankind was to have a water-carrying system. The water-closet system, however, must be carried out with great perfection. When water entered houses, from howsoever pure a source, and passed through to become sewage, it immediately became noxious, and should be disinfected at the earliest possible moment. Taking that as an initial

principle, the question arose as to the process of precipitation of fæcal matter, for in fæcal matters there were many products, such as mucus, eminently calculated by nature to resist the operation of water. Mucus, as in the case of frogs' spawn and the covering of fish spawn, was a substance particularly capable of resisting water, and unless it was precipitated it was liable to generate diseases. He need hardly direct attention, from a medical point of view, to the way in which the mucus of gonorrhœa might be propagated to the eye and to other membranes, or how typhoid mucus might be propagated if taken into the system. It was therefore important that the matter which passed into the sewage should be precipitated, thrown down, and destroyed at the earliest possible moment. One of the great points in the discussion was how to precipitate that mucus. The fæcal matter might be precipitated either by lime, by alumina, by the salts of alumina, or by animal charcoal, then by soluble phosphates, or by a host of other similar substances; but none of those substances were perfect, and the urea was left unprecipitated in a solution of water. Having got sewage with the fæcal matter precipitated, it would be conceded as a principle that it might be beneficially given to a thirsty plant, that was to say, to a plant in a condition to take water. If one drop more water were added to that plant than it could take, then the plant would be damaged, its functions injured, and its products bad; and he would challenge any one present to say that there was any sewage farm, carried out continually and persistently, that was doing all the good it might to the plants upon that farm, but was not actually doing a positive mischief. Those general principles showed this, that the sooner the noxious elements of sewage were decomposed and destroyed the better. The next proposition, enunciated by one of the speakers, was, away with it to the sea, and when this was done it must be far away into the sea, because if it was put into the sea, as at Brighton, some distance from the shore, the difference of specific gravity was so great between sewage and salt water that it rose to the top; and he had seen for ½ mile or 1 mile in length the sewage floating at the top of the water—a nasty and a noxious thing. As a principle sewage works in towns must be carefully done. Typhoid fever had increased of late years, although typhus fever had gone down. Typhoid fever was eminently the disease of the water-closet system, and was manifestly the great test as to the perfection of sewage arrangements. Good and great as were the results of the work of the Registrar-General, they did not meet the occasion with which they had now to deal. It would be well that every town should post weekly the

number of those diseases which came by sewage, and particularly typhoid fever. During the last twelve months Croydon alone had had more than one hundred cases of death from typhoid fever, and eleven hundred cases of typhoid fever; and when it was considered that of those cases each man had been ill upon an average ten weeks, and when this loss to the family and to the community was calculated, it would be seen that there was no cheaper thing to the entire community than that of keeping typhoid fever at a distance. Some people thought that by running rivers of water through sewage the difficulty was overcome; but mucus was untouched, indeed was not intended by nature to be acted upon by water. Contagious poisons, as far as could be determined, were conveyed by mucus, and hence it ought to be taken as a primary principle that those poisons must be destroyed at the earliest moment after they had passed into the sewage. He would not go into the extent by which the cost of this process might be reduced. It had been said, and this agreed with the result of his own inquiries, that it would cost at least 6*d.* per head of the population to precipitate the vicious matters in the sewage, but, whatever the cost, it ought to be done. Not only had known cases of disease to be dealt with; outbreaks of serious fever continually occurred; and he need hardly point to the case that impended at this moment —the rise of the plague along the valley of the Euphrates. Were people prepared to meet this epidemic if it should reach this country, when some towns were spreading the excreta of their population over hundreds of acres of surface? He actually knew of a case in which sewage was being carried to acres of watercresses, simply that a town might obtain about £120 a year in order to reduce their expenses; and in that way the excreta might be spread over those watercresses and be distributed to the population of other cities. After the fæcal matter was precipitated the residuum must go into the earth, and then pass through a considerable amount of porous strata, where it might be ultimately destroyed. That it was so destroyed was shown by the deep springs of London, where the water, having filtered through the chalk, contained, as was found in the well at the Bank of England, the smallest possible trace of organic matter. Care must be taken that the residuum really went through the earth, and that the operation was carried out in such a way as not to create a nuisance. A town had no right to take its sewage into another district, and there, on the plea of the common good of humanity, cause such an amount of damage to others that it became a nuisance. All chemical processes for obtaining manure from sewage should be looked upon as subsidiary. As far as his experi-

ments had gone, he found the manures that had been formed from sewage were almost useless. They did not produce effects equal to their theoretical equivalents. He had applied some kinds on beds in his experimental garden, crossing them diagonally, and crossing them in patches, but after he put in a valuable amount of the artificial manures made from sewage, he could not tell from the crops where they had been put on. Why they should be so impotent he could not tell, but their value could be tested by experience alone. If, as it ought to be, any benefit could be got, by making artificial manures, to lessen the cost of the proceedings, seek it; but, above all things, let nothing be done to sacrifice the public health.

Mr. Law said, having examined with some care the figures contained in the Appendix to Mr. Shelford's Paper, he was struck by an apparent anomaly in the estimated values of the precipitated phosphates, and had prepared the following tabulated statement to which he would direct attention:

—	Estimated value of Phosphate contained in Manure.	Estimated value of Phosphate derived from Sewage.	Estimated ultimate value of Phosphate added to Sewage.	Original actual Cost of same.	Increased value assumed to result from Manipulation.	
					Actual.	Per cent.
	A	B	C	D		
	£.	£.	£.	£.	£.	
Experiment No. 1 . .	225·61	41·45	184·16	120·71	63·45	52·6
„ No. 2 . .	298·28	41·45	256·83	211·87	44·96	21·1
„ No. 3 . .	385·57	41·45	344·12	212·71	131·41	61·8
„ No. 4 . .	246·36	41·45	204·91	215·80	..	..
Mean.	288·95	41·45	247·50	190·27	57·23	30·1

Column A showed the values, as estimated by Mr. Shelford, at 3*s*. 3*d*. per unit, of the phosphates contained in the sewage. Column B showed the estimated values of the phosphate originally contained in, and derived from, the sewage itself. The average quantity of phosphoric acid contained in ordinary sewage had been variously estimated; by Dr. Hoffman at 1·85 grain per gallon, Dr. Letheby 1·74, Dr. Way 1·68, and by Dr. Voelcker at 1. It was stated in the Paper that the sewage experimented upon was a weak sewage, but, to be on the safe side, he had taken the highest valuation of 1·85 grain to the gallon, equivalent to 4 grains of tricalcic phosphate. This at 3*s*. 3*d*. per unit for 10,000,000 gallons gave £41·45, as shown in column B. Deducting 'B' from 'A,' there remained the value shown in column C, viz., the estimated ultimate value of that portion of the phos-

phate originally added to the sewage as contained in the manure deposited; but if this was compared with column D, the actual cost of that same phosphate, as stated in the Paper, it appeared that the process of dissolving the phosphate in the sewage and depositing it had increased its value, in the first experiment 52 per cent., in the second 21 per cent., and in the third 62 per cent.; the mean of the four experiments being 30 per cent. It did not appear that this increased value arose from an increase in the quantity of the phosphate, but rather from the higher value per unit assigned to it. For instance, in the third experiment, 32 lbs. of phosphate were used, costing 1*s.* 5*d.*, whereas the phosphate obtained was barely 18 lbs. and was valued at 2*s.* 7*d.*, or an increase of more than three times its value by manipulation. Now considering that the phosphate contained in these manures was combined with from 66 to 80 per cent. of what had been significantly designated 'profligate associates,' he could not but think that the value of 3*s.* 3*d.* per unit did not express the true money value to the farmer of the phosphates contained in the manure derived from sewage, and that the mode of estimation adopted was likely to lead to fallacious results.

Mr. C. E. Austin observed that for the last ten years he had advocated a system of extracting the solid matter from the sewage at the earliest possible moment, collecting it in the branch drains, and not allowing it to go into the main sewer. This he had suggested might be accomplished by strainers changed and removed daily from the drains, and conveyed to a market garden, or some other place where the solid could be used as manure. This plan was adopted by a seaside colony commencing building, and, having been in work for the last nine years, had given satisfaction, and was now to be extended over the whole district within the jurisdiction of that Improvement Commission. He need not mention the difficulties of promoting a system of that sort, but having tried experiments with this system in two or three other places, no objections had been raised to the results. In one case, where it was tried for a year and a half in a town on the Thames, and where the analyses both of the sewage and the effluent waters were regularly published, although it gave perfect satisfaction, the local authorities finally abandoned it, and said, "If we adopt your system we shall have to pay for it, and afterwards we shall have to pay for the Government system," for a combined system of drainage was being held over them in terrorem. The process was a cheap one, costing only 2½*d.* per head for a population exceeding five thousand, and the solid matter

could be used as manure. An acre of land would suffice, if required, to absorb the solid manure of a population of ten thousand for one year, and if that acre was planted with roses and strawberries, interlined with cabbages and celery, &c., the manure would be sufficient for four years; so that for a population of ten thousand only 4 or 5 acres would be needed to dispose of the solids. The admixture of silicate of soda with the fluid destroyed the mucus in a great measure, and by a second process of filtration at the outlet, or by a small surface irrigated, an effluent water equal in purity to the original Thames Conservancy standard was obtained. By extracting the solids at the earliest possible moment, the remaining contents of the sewers were more easily dealt with. The effluent water of the sewer, of which an analysis was shown, was purer than any sample of effluent water he had ever seen, showing that there was a great deal in extracting the solid matter before it was disintegrated. There was also the advantage that a greater fall could be given to the branch sewers, in consequence of a less fall being required for the main sewer, in which there would be scarcely any matter to form a deposit.

Mr. Abernethy, Vice-President, said, having for some years past paid attention to the question of the disposal of sewage, he had arrived at the conclusion that by the A B C system, the lime process, and other modes, an effluent water might be obtained of sufficient purity to be passed into rivers of ordinary volume. He was also convinced, from a certain amount of personal experience, that the solid residuum could be applied to agricultural purposes with benefit, but not that it could be at all regarded with a view to profit. Nor should town authorities regard it in that light; for if it cost 1*s.* per head per annum, it was to the interests of the population that the cost should be faced, and the sewage disposed of in the best possible manner. He felt strongly the necessity of preventing the pollution of rivers by sewage; and that even where sewage was passed into the sea, great care should be taken in the selection of the outlet, that it should be passed into the sea, at a part of the coast where the current would carry it into deep water. He had not yet had the pleasure of reading Sir John Hawkshaw's report on the disposal of the sewage of Glasgow; but if it was correctly described in a leading article in "The Standard" of the 3rd of April, 1876, he must congratulate Sir John Hawkshaw on the bold way in which he grappled with the subject, viz., by discharging the sewage of that city into deep water at Farland Head, far beyond the embouchure of the river Clyde.

On the 7th December last, he had stated at the Institution that the discharge of the sewage in the Thames at Crossness had had the effect of depositing a stratum of deep black mud over the original bed of the river, and that that stratum of fœtid mud was gradually extending up the river to Woolwich and beyond. That statement was met by Sir Joseph Bazalgette in these terms: "He was surprised to hear it stated that in consequence of the drainage of London, a large accumulation of mud had taken place in the river at the outfalls, and that there was a prospect of it impeding the navigation. He had never before heard such views expressed by any member of the Institution. He would ask whence the facts were gathered on which these conclusions were grounded. Since the metropolitan outfalls were first opened, he had had soundings taken in their neighbourhood, and he found that there was, at the present moment, less accumulation of mud than there had been before the outfalls were established."[1] Subsequently Sir Joseph had furnished a copy of his report, in answer to a letter from the Conservators of the Thames, dated 29th July, 1874, in which he stated: "By a comparison of the Board's soundings it appears that between the year 1867 and the present time, there has been a positive scour and improvement in the depth of this part of the river, to the extent of more than 300,000 cubic yards, or in other words, that part of the river is now 10 inches deeper than in 1867. This is the true test, and this figure represents practically the improvement which has taken place in the deepening of this part of the river since the opening of the Board's outfalls up to the present time. Although, doubtless, sewage is mixed with the mud deposits here and for several miles above and below London, the evidence above quoted goes to show that the sewage discharged into the river at Crossness tends to scour it rather than to form deposit."[2] That statement was so opposed to natural results and his own experience, that he sought further information from the officials of the Thames Conservancy Board, in order to account for the extraordinary phenomenon, that the sewage deposited at Crossness Point tended rather to scour the channel of the river than to form a deposit. He had been supplied with a list of the soundings, from which it appeared that the condition of things at the outlet of Crossness in 1861, previous to the discharge of the metropolitan drainage into the river was this—that immediately opposite Crossness, on the south side of the river, there existed a deep-water

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 209.

[2] *Vide* Metropolitan Board of Works, Letter, &c., No. 718, July 1875.

channel, and also an extensive anchorage used by colliers, and termed the Colliers Section, No. 3. That anchorage no longer existed, nor did the deep navigable channel which then ran on the south side of the river, but in place of that a huge mud-bank had been formed of black deposit, undoubtedly from the sewage, so that the soundings were reduced from 22 feet to 10 feet, and from 22 feet to 11 feet, the difference extending far into the centre of the river. The survey made by the Conservancy Board last year showed most distinctly that the stratum of black mud was gradually extending up the river beyond Woolwich, and that the original clean gravel bed no longer existed. Sir Joseph Bazalgette had stated, in the discussion and in his reports, that at Crossness the general sectional area of the navigable channel had not diminished. That was accounted for in this way: most extensive dredging had been carried on on the northern side opposite Crossness by the Trinity Board to obtain ballast for shipping, so that the deep-water channel was now on that side of the river. That channel might be maintained as long as dredging was resorted to, but it would silt up when the dredging ceased, and it would cease when the gravel was impregnated with mud. He believed, therefore, it would be found necessary, probably at no distant period, to carry the sewage of the metropolis beyond the mouth of the Thames and to the sea into deep water, where it would no longer be a nuisance; for if matters remained as at present, the tidal flow, passing over a long continuous fœtid bed of mud, must pass up to the city of London in a contaminated state. As a proof of the contamination of the river, he was informed that while fish used formerly to be kept alive in the well-boats at Barking, they had subsequently been removed to Erith, then to Gravesend, and now they were obliged to be kept at the mouth of the river. He believed a large portion of the lighter sewage was carried by the flood tide high up the river. A bank of black deposit, visible at low water, had accumulated within a recent period in front of St. Thomas's Hospital, and being analysed by Dr. Letheby, was found to contain traces of sewage.

In discharging sewage into the sea, it was necessary that great care should be exercised in the selection of the outlet. At Margate, after a long discussion upon competing schemes, he was informed it had been resolved to discharge the sewage about 1½ mile eastward of the town into the sea, beyond a reef which projected at right angles to the shore, forming a low-water groyne. Eastward of that natural groyne there was another of the same character, and between them a sandy bay, so that the sewage discharged between those two natural groynes at low water, would be cooped

up between them, and would remain permanently deposited at that point. Near high water, when the current was exceedingly strong, a portion would no doubt be carried back to Margate, and gentlemen enjoying the pleasures of natation might find articles parted with long ago in close proximity to their persons. Taking a broad view of the subject, the points to be considered were, the selection of proper outlets for the discharge of sewage, the best and most economical mode of utilising it for agricultural purposes, and of removing it from rivers, so that they might be no longer polluted, but restored to something like their original purity.

Sir JOSEPH BAZALGETTE said the Papers treated of two distinct modes of dealing with the excreta of towns, although they had been a good deal mixed up in the course of the debate. The first dealt with the appliances for receiving and removing fæcal matter from houses in a solid form, and taking it away in carts. The second proposed to extract the solid matter from the water, which had been made the carrier for its removal from towns. Dealing with the first Paper, he was struck by a statement that five-sixths of the whole of England was under what might be called the dry system. Even if a large proportion was subtracted for the rural districts, and attention was confined to towns, there would remain a number of places dealt with, according to this view, by the system of middens, pails, or devices of that kind. If that were so, it was important to have the best appliances for collecting and removing the deposit. For a long time much of the sewage must be so treated; but, in his opinion, that system was altogether unsuited to the present age. It was, if he might use the expression without giving offence, a barbarous system—a system by which the closet must be out of the house, the excreta must be exposed in the closet until covered from time to time with ashes, and men must come round to the house once a week with the cart to remove it to some place of deposit, where it must remain until it could be got rid of. It was not only a barbarous system, it was also a costly one. It was stated that at Birmingham the cost of the removal was 1*s.* per head per annum. That appeared to be a small amount, and very reasonable; but in London there was a population of four millions, and 1*s.* per head meant £200,000 a year, which capitalised at 5 per cent. was £4,000,000; that was equal to the cost of the Main Intercepting Sewerage of London, and such an expenditure would therefore double the Intercepting Sewerage in order to perpetuate a barbarous system. If such a system were introduced at Bournemouth, Torquay, Brighton, or any similar town, the place would be ruined. The

only really proper system fitted for this country was the removal of all sewage by water. The water came quietly and silently into the houses and carried away everything decomposing and that was of a disagreeable character, and it was no longer present to the senses, and there was no annoyance by meeting people in the streets taking it away. Some people would say, "Oh, there is the difficulty of the ventilation of sewers; typhoid fever, and all sorts of evils, arise from the water system;" but the best practical answer to that was the sanitary state of London. Though it had the largest population that had ever been congregated together in the United Kingdom, there was no other town of the same class more healthy, and the air of which was more pure. The smell in the streets of continental towns which had not the water system would be found much more disagreeable than in London, and the death rate was higher. He therefore contended that the water system was the only civilised and proper way of getting rid of the sewage of large towns. The outfall could be placed wherever it was desired. General Scott, who had devoted a great deal of time and talent to the consideration of the subject, and had worked hard at a mode of extracting solid sewage from liquid, had stated that the conclusion he had arrived at was that an outfall into the sea, or some other place where the sewage would for ever be disposed of, would be the best method that could be adopted. In previous debates he had heard highflown ideas about the value of sewage, and the profit to be made out of it, but it seemed now to be admitted that it could not be dealt with with a view to profit, and expenditure must be incurred.

It had, again, been stated by Mr. Abernethy, that the discharge of the metropolitan sewage at the outfalls had had the effect of filling up the bed of the Thames. Even if correct, this would form no real argument for a change in the plan of dealing with the sewage involving a large expenditure. All that would be necessary in that case would be a little extra dredging; but Sir Joseph Bazalgette thought that objection had been answered on the last occasion when it was raised. In the year after the opening of the outfall sewer at Barking Creek and Crossness, in 1867, there was a decrease of 480,000 cubic yards in a length of $\frac{3}{4}$ mile of river opposite the Crossness Outfall at Halfway Reach. The following year there was an increase of 142,000 yards; the next year a decrease of 216,000 yards; then an increase of 277,000 yards, and in the following year 279,000 yards; again a decrease of 260,000 yards, and the next year 53,000 yards, making a total decrease of 311,000 cubic yards between 1867 and 1874. That

showed that, if anything, there was a scour at the outfall, but there were some more important influences at work, such as those due to the rainfall and the general scour of the river, rather than the amount of sewage poured into the river. Some of these causes might be found in the continuous washing away of the alluvial banks by the tidal waters, or might be due to the discharge into the river of silt from the docks and from other sources, or to improved land drainage into the upper reaches of the Thames, or soil brought down from the uplands by heavy rains, or to the effect of piers or other works in the river. The positions of shoals so formed might be expected to shift, as indeed they did, in accordance with the variation in the strength and set of the current, arising from change in the direction and force of the wind and quantity of upland and tidal water. An inquiry was held some years ago, and it was determined that if there was an increase of deposit at the outfall, the Thames Conservators should be entitled to call upon the Metropolitan Board to dredge so much as was added to the bed of the river; but the Thames Conservators, from that date to the present, had never exercised that power. If it were not a little beside the question, he could show also that it was not only the fact, but the logical result, that sewage could not deposit in the bed of the river.

With reference to dealing with sewage at outfalls, where a clear outfall could not be obtained, but where the sewage had to be dealt with first, then some one or other of the processes which had been laid before the Institution might be adopted. Those processes, however, had not been so satisfactory as could be desired. One gentleman advocated the lime process of precipitating solids from sewage at the outfall. This was perhaps one of the oldest methods, having been in operation more than twenty-five years. It was quoted in the Paper as being in operation at Birmingham, and in the outskirts of that town there were large precipitating reservoirs, into which milk of lime was poured, and the sewage deposited from the effluent water. That deposit was removed from time to time by the best class of machinery that could be designed, and was thrown upon several acres of land which were covered with sewage sludge. That sludge was allowed to dry, and, when sufficiently dry, was dug into the land, and crops raised upon it. Such an operation might be tolerated in the outskirts of a manufacturing town, but it would be highly objectionable and most detrimental if applied to watering-places. At Birmingham the Corporation had tried to get a sewage farm on which to deposit the sewage from the tanks and irrigate the

land; but they had failed, and within the last twelve months an action had been brought against them by Sir Charles Adderley for polluting the waters of the river Tame and flooding his land, and they had to pay him a large amount of compensation. The fact was the effluent water could not be sufficiently purified, especially in times of flood. Again, with regard to Leicester, where the system had been in operation many years, he was being consulted with a view to establish a sewage farm there. He visited Leicester a few months ago, shortly after heavy rains, and he found the machinery had stopped. On asking the reason, he was told that it was on account of the heavy rains. There was so much water coming down that it could not be dealt with, and it was allowed to go into the river and over the lands flooded by it. This was the great difficulty with all these different processes. One gentleman, who advocated the A B C process, had spoken of his experiments at Crossness. He said that he had for three months been trying how far the sewage could be purified, and that if he had only had three months more he could have shown how it could be made to pay. What were the facts of the case? That gentleman had from the 1st of January, 1870, to the 30th of November, 1872, and during that time he only dealt with $\frac{1}{700}$th part of the sewage of the metropolis. If he was not satisfied, as the result, that the process could only be worked at a great cost, and could not be made to pay, certainly those persons who were impartially looking on were; and another two years, or a much longer period, would probably not have satisfied him that it could not be made to pay. He did not propose to speak of the various modes of dealing with sewage by precipitation. Most of them could be used under certain conditions, and there were circumstances where they must be had recourse to; but it could only be done at great cost, and, after all, was only a palliative and not a cure. He believed that the purification of sewage by irrigation was the most satisfactory mode of disposal, but still it could only be done at a loss, and was a method to be resorted to only when no better could be found. He concluded by expressing his conviction that the sanitary question—the removal of the sewage of towns in an inoffensive and healthy manner—was the first thing to be considered, and that it could be best done by water carriage. The problem of the disposal of sewage was not yet solved, and until it was solved the best thing to do was to get rid of it by an outfall which would carry it far away. The members were greatly indebted to the gentlemen who had discussed the question so earnestly, and had given so much time

to its consideration, for that was the way in which things were eventually brought to perfection. In the meantime their first duty was to study the sanitary question, and leave the matter of profit to be settled hereafter.

Vice-Admiral Sir FREDERICK NICOLSON said he could in every respect confirm the facts stated by Mr. Abernethy. There could be no question that if a large quantity of sewage was poured into a river, there must be a deposit somewhere. The latest surveys in the neighbourhood of Crossness showed that a shoal was undoubtedly being formed precisely opposite the outfall. No doubt Sir Joseph Bazalgette's figures were correct from his point of view; but they resulted, as Mr. Abernethy had stated, from considerable dredging having been carried on on the opposite side of the river. Sir Joseph had alluded to the fact that he had not yet heard from the Conservators of the Thames that they required that part of the river to be dredged. The Conservators had for the last few years been carefully watching this part of the river; they had taken careful soundings, and had had the deposits analysed; and he felt confident that it would not be long before it would be necessary to have a large amount of dredging done, not only close to Crossness, but in the reach above. He believed when that time arrived, both the Board of Works and the Conservators would jointly do all in their power to keep the river as pure as they could, and, above all, to keep the navigation always open.

Mr. LEMON thought the injudicious advocates of sewage utilisation had done more to retard the solution of the sewage problem than the strongest opponents. The same system had been recommended in every place regardless of local circumstances, and the result had been a considerable financial loss. He agreed with General Scott that the best thing to be done with sewage was to throw it away: that it was no longer to be looked upon as something to make money out of, but must be got rid of as quickly as possible. After seeing every process in the kingdom for dealing with sewage, he had arrived at the same conclusion as Sir Joseph Bazalgette, viz., that the dry-carriage system was a barbarous one, and, moreover, it was costly; for where the dry-closet system had been carried out there was also a system of sewers to carry off the slops. Having had to lay out a scheme for draining a large district, where there were some strong advocates of the dry system, he took the trouble to make a few calculations as to what would be the saving in the area of the sewers required if the dry system were adopted, and he found that the same area of sewers was requisite for the dry system as for the water-closet system. Both systems

were in vogue at Birmingham; but in that town, according to the Reports of the Sewage Inquiry Committee, no less than £250,000 had been laid out for the drainage. Again at Manchester, where the dry system had almost entirely been adopted, the cost of the sewage works had been £340,000. This would not be so much complained of if the dry system were a good one, but nearly all the large towns adopting it had had injunctions against them for polluting the rivers. He therefore considered that the advocates of the dry system had not solved the sewage problem. The value of the manure had been put at 2*s.* 6*d.* per head. As far as his experience went that was a theoretical value, and never had been and never would be realised. It was a value which no farmer could afford to give for dry sewage, because, being in such a large bulk, the cost of cartage and labour was proportionally greater, and it was to his interest to buy a high-class and more concentrated manure. Being anxious to try this question at one time, he gave some of these low-class manures to a scientific farmer, who told him he did not care about having more, and that for such manures he certainly could not give more than 2*s.* or 3*s.* a ton. That manure was valued by theoretical chemists at 30*s.* a ton. The great difficulty in the precipitating process was the disposal of the sludge. Drying it was sure to be more or less a nuisance, and the system adopted at Birmingham appeared to be the less objectionable of the two. One fatal objection to the precipitating system was that the ammonia was lost, and it was that alone which gave the product any value.

Mr. Milburn explained the dry-sewage system, as carried out by the new Town Manure Company at Bilston, which proved that two of the conclusions arrived at in Mr. Redgrave's Paper were correct: first, that it was possible to effect the collection of excreta without creating a nuisance; and, secondly, that it was possible to procure from excreta collected on the dry system a concentrated manure which would repay the cost of collection. The Town Manure Company was originally started at West Bromwich, but the system not succeeding there, application was made to his firm to erect the machinery for treating and drying night-soil. At that time the Company had not taken adequate steps to overcome the difficulty of preventing a nuisance arising from the noxious vapours, and the town authorities therefore gave them notice to go. Previously to this, however, the commissioners of Bilston had inspected the system, and had had thoroughly explained how the nuisance could be avoided, and had come to terms with the Company to start operations. The machinery was erected for drying the excreta, and the Milburn Company's process for consuming the noxious

vapours was also applied. For nearly a year the manufacture had now been continuously carried on, without creating the slightest nuisance, while the Government inspector had reported favourably upon it, and on the condition of the town under the Company's management. The population of Bilston was about twenty-five thousand, and the number of privies more than two thousand. The company were now clearing the whole of the night-soil of the town; and when all the privies were supplied with the new tubs, there would be as nearly as possible 130 tons of raw night-soil produced at Bilston weekly, yielding from 13 to 14 tons of finished manure, containing, according to an analysis by Dr. Voelcker, nearly 8 per cent. of ammonia, and 5 per cent. of phosphate of lime. This was a valuable manure, far more so than had hitherto been obtained from excreta. The total cost of collection and production was as nearly as possible £55 a week, and for that they could obtain 13 to 14 tons of manure, worth £7 10*s.* to £8 a ton. He therefore thought the Town Manure Company had so far solved the question, that they had demonstrated to a certainty that a concentrated manure could be produced from night-soil without causing the slightest nuisance, and that the manufacture would yield a large margin over and above the cost of production. The drying machinery had since been considerably improved, so that 1 lb. of coal would evaporate about 7½ lbs. moisture, or nearly 50 per cent. more than it did previously.

Mr. Monson said the primary consideration with regard to the disposal of sewage was the health and convenience of the community at large; and in this light the water-closet system had great advantages over all others, the removal from the premises being effected by the mere pulling of a handle or the turning of a tap. The waste water from houses and manufactories was generally sufficient for transport, and the nuisance occasioned by conveying the excreta through the streets was abolished. The best, and indeed the only, method of really purifying sewage was first to remove the solids, and then to pass the liquid through aerated porous soil, upon the intermittent principle, the land being properly drained. Stiff clay soil was unsuited for the purpose, and sewage applied to such land left the land scarcely better than if it had only been filtered. Pail-closets were opposed to sanitary principles, and to every feeling of delicacy and refinement. They depended for their efficacy upon the night-soil man, whose visits were always inconvenient and unpleasant; and the pail being used by several persons, was disgusting; and its contents gave off noxious odours which were injurious to health and an annoyance to the

inhabitants of the house. The cost of this system, too, was great. First, there was the cost of horses, carts, and pails; then the annual outlay for repairs, team and manual labour, and, finally, the expense of manufacture and disposal. On the other hand, the water-carriage system was cheap and efficient. The death-rate of London, with its water-carriage system, was 26 per 1,000, whilst that of Manchester, with its pail system, was 34 per 1,000.

Mr. RUSSELL AITKEN remarked, through the Secretary, that he had been for some years Engineer for the city of Bombay, where, as usual in Indian cities, the night-soil was collected by hand. When he went to Bombay in 1866, from one part of the city containing 500,000 inhabitants, the amount of night-soil taken away did not exceed forty carts, or about 30 tons. Afterwards, by an improved system of collection, and the use of the new style of air-tight night-soil carts, the amount removed from the same district was increased to 120 tons, or to more than four times what it was formerly. The cost of collecting the whole of the night-soil of a population of more than 700,000 persons was, for the year 1867, about £60,000 per annum, being at the rate of about £1 per ton of night-soil. When the night-soil had been collected it was flushed out to sea, and floated down the harbour at high water. In 1867 he proposed to substitute the water-carriage system for the removal of night-soil, instead of the present inefficient mode of collecting, or rather attempting to collect it, by hand every morning. He was earnestly pressed to adopt various projects for the so-called utilisation of sewage, such as irrigation, &c. He, however, adhered to his plan for throwing it into the sea at that part of the island which was most remote from the densely inhabited parts of the town, and where the sewage would be swept by the ebb-tide well out into the Indian Ocean. From his experience of the water-closet system when applied to warm climates, he was of opinion that it was much more healthy as well as cleaner than the system of removal of night-soil by hand. With regard to the pail system, adopted by some towns in England apparently with success, when compared with the water-closet system, he had no doubt but that if the water-closet system were used in separate little houses, as was absolutely necessary when the pail system was adopted, it would be found that the water-carriage system was much the healthier mode for removing night-soil. It was the abuse of the water-closet system which had led to the disastrous outbreak of fever for which the use of this system was made responsible; and if a regulation were passed that

every water-closet should be provided with a large ventilator or window, communicating directly with the outer air, little or nothing would be heard of the injurious effect of sewer gas, whilst the health of the community would be materially improved.

Mr. EACHUS stated, through the Secretary, that the Authors of the Papers appeared rather to have over-estimated the returns obtainable under the dry and precipitation systems. Mr. Redgrave stated that the annual cost of the removal of ashes and excreta was 1*s*. per head of the population, and he estimated the value of the pail stuff at 2*s*. 6*d*. per head. Mr. Shelford put the cost and assumed value of the manure produced by Whitthread's process at £3 3*s*. and £3 18*s*. 6*d*. per ton respectively. Both these estimates showed a profit of from £1,200 to £1,500 a year in the case of a town of 20,000 inhabitants—a result not obtained in practice. Mr. Eachus found the results of the last six months' trial at Edmonton to be that both irrigation and a precipitation process—that known as Hille's —had cost the local board in each case about the same, namely, £6 per million gallons treated, or 1*s*. 2*d*. per head per annum, inclusive of interest on capital expended, for the two systems. The farm was let to a yearly tenant, and up to the present time had only been partly prepared; in the comparison of the two systems it had been assumed that the whole amount necessary for the completion of the farm had been expended in addition to the actual expenses. With these facts before him, and bearing in mind the difficulty of disposing of the manure or sludge in the case of the dry and precipitation processes, he was of opinion that irrigation, or, as it was sometimes paraphrased, intermittent downward filtration, was the system best adapted for sewage utilisation, especially as, although taking the cost as being the same for the two systems, the productive power of the land was increased much more, and the country thereby became indirectly a gainer. Of course no system could be universally adopted, as if the whole of the sewage of the country were utilised by irrigation there would be from $\frac{1}{8}$ per cent. to 1 per cent. of the whole country under sewage. Hence the advantage of dealing with some of the large centres of population in the manner in which London had been, and Glasgow was recommended to be, dealt with. Chemical processes were most useful in combination with irrigation, or where that system could not be adopted and the standard of purification required was not a high one.

Dr. J. H. GILBERT observed, through the Secretary, that there could be no doubt whatever that the interception or dry processes referred to by Mr. Redgrave were an immense improvement

upon the old midden-pit or common privy systems; but no such plan could be accepted as a solution of the sewage difficulty. About four-fifths, or more, of the manurial value of human excretal matters were due to the urine. It was a desideratum with all such systems to exclude as much of the urine as possible, and the complete separation of the liquid from the solid dejections had been recommended. Of course, this would much reduce the value of any dry manure so produced, which was already so low as not to be worth more than its carriage beyond the immediate locality. Without such special separation, at the outside about one-third of the urine would be collected with the fæces. Under any such dry system there was, therefore, from two-thirds to the whole of the urine, besides all wash and other house drainage, still to be dealt with; and if the liquid had to go into a stream which served as the water supply for other populations, sooner or later purification would be enforced. Passing the liquid through land was not only the best mode of purification, but promised the greatest return for the constituents it contained—whether profit to the towns, depended on many local circumstances. Then as to precipitation methods. There could be no doubt that any one of those referred to by Mr. Shelford would be a vast improvement upon doing nothing whatever with sewage that had to be turned into an open stream. No such plan was, however, likely to collect more, and would generally collect less, than one-fourth of the nitrogen of the sewage in the solid manure. This one-fourth was, moreover, the least active and least valuable part. These plans also, as a rule, carried down the phosphates, but in a precipitated, not in a soluble, form; and in more than one scheme soluble phosphate had been used, and was converted from this more valuable into the less valuable precipitated condition. The estimates of the value of the nitrogen reckoned as ammonia in such a manure, containing only from 1 to 2 per cent. of it, at the same rate as was provided in guano containing about 12 per cent., and in a much more soluble condition, was entirely fallacious; as also was the valuation of precipitated phosphate at 3*s*. 3*d*. per unit. Would, then, such precipitated manures pay for their manufacture as such? He thought not. If the process were adopted mainly as a means of purification, what was the result? About three-fourths of the nitrogen of the sewage would remain in the liquid. This would exist, in the main, not as nitrates, but as ammonia and soluble organic compounds. This liquid, with all other house drainage, remained to be dealt with. He did not think that such a liquid would eventually be allowed to run into a water-supply stream. Passing it through the land would best purify it,

and would yield the largest return. If the sewage were employed for irrigation, the less taken out of it, beyond the sludge, before use, the better; and if the phosphates were removed, they should be returned either to the sewage or to the land irrigated. In fact, where irrigation was to be eventually adopted the less effective the precipitation process the better; indeed, the exclusion of the natural sludge was all that was desirable. He was by no means unconscious of the many difficulties involved in the general adoption of sewage irrigation, but he believed if rivers were to be kept from pollution, it would eventually have to be adopted, wherever practicable, before the liquid was discharged into them.

Mr. Gilbert Redgrave, in replying upon the discussion, said he wished, in the first instance, to repudiate the idea, which seemed to have suggested itself to several of the speakers, that he appeared as the advocate of an interception system as opposed to a water-carriage system. He had carefully guarded himself against this in the Paper. Finding how large a portion of the population was dependent upon some interception system, he had endeavoured to show that the subject was worthy of the careful consideration of the engineer. It was too much the rule at the present time to lay down a hard-and-fast law that, from an engineering point of view, there was nothing at all worth thinking of but some system of water-carriage, and to assert that water and nothing else but water had been designed by nature to remove human ordure. It needed neither the advocacy of Sir Joseph Bazalgette nor of Mr. Monson to persuade them, for doubtless every one was prepared to admit, that the water-closet was the most decent, the most comfortable, and the most perfect contrivance for the removal of human excreta from habitations. But, notwithstanding that the dry-collection system had been denounced as "barbarous" and "incomplete," it must be remembered that it was sufficient for all the requirements of by far the largest portion of the inhabitants of this country, and that it was used with cleanliness and comfort even in the houses of the wealthy, while the water-closet was the comparatively modern luxury of the few. But beyond all these considerations of mere comfort, he had endeavoured to show that the persons occupying the "uncivilised quarters" of towns were not easily persuaded to use mechanical contrivances of any kind; and for them, he knew by experience, any form of water-closet was quite out of the question. In nine cases out of ten the trap became stopped up with filth, and the first remedial measure adopted by the "lady of the house" was to put the kitchen poker through the bottom of the pan, which

doubtless had the effect of unstopping it for good and all. The best arrangement for such a neighbourhood was a shallow midden of small dimensions, or some form of pail, with quick and therefore frequent removal of the contents. It was useless to talk about "invading the privacy of the house," among a population possessing but one privy to every four houses, and thinking themselves well off to get that. Why, such people only complained about overcrowding when the separate families, living in each room, sought to take in lodgers! People who made objections of the above kind had never studied the question *in situ*. The Author's only attempt had been to bring under the notice of the meeting what had been done by the officers of the Local Government Board, and to show what was being effected for bettering the "conditions of life" in large manufacturing towns. Dr. Voelcker had cast doubts upon the possibility of making any profit out of the excreta collected on the dry system, grounding his opinion upon the experience gained in Holland and Belgium from the sale of fæcal matters in their natural condition. He had, however, admitted that it might be possible to extract salts of ammonia from urine, as a paying process. Now Mr. Redgrave had shown that the profit he had spoken of was to be derived by extracting the fertilising elements from the liquids and presenting them to the farmers in a concentrated form. He was glad to learn from Mr. Milburn that actual working on a large scale at Bilston had confirmed his views concerning the profits to be derived from dealing with dry sewage. Mr. Alderman Taylor had found fault with the statement that the Rochdale system was founded upon the process of M. Goux. Mr. Netten Radcliffe's report was his authority, but he was glad to accept the alderman's correction in the matter. While a great admirer of the Rochdale system, he could not agree with the present plan of manufacturing manures there, for the process of absorbing the urine with ashes degraded its value too much. While on this question, he might remind Mr. Smee that he was opposed in principle both to the ash and to the earth-closet system as now practised. He objected strongly to the admixture of the liquids and the solids in the receptacle, and considered that if deodorants were employed, they should be used, in small quantities, to the solids alone, and be of such a nature as not to diminish the value of the fæces as fertilisers. Rochdale deserved all praise, he thought, for having led the van in the way of improved midden construction, and improved methods of collecting and treating dry-sewage. When referring in his general conclusions to "improved" midden con-

struction, his remarks were intended to apply to some form of pail- or tub-system, and not to some alteration of the old-fashioned fixed receptacle. Mr. Fowler had found fault with the great expense of the tub-closets at Leeds. He thoroughly agreed that if the cost of collecting the night-soil amounted to 12*s.* 3*d.* per ton, it was high time that the authorities there should learn what was being done elsewhere; in many other towns the cost was less than half the figures quoted. Mr. Fowler complained that no mention had been made of the systems in use at Salford; true he had omitted to speak of Mr. Fowler's invention, which might, he considered, be useful, but which, however, was not a dry-closet, and could not be included among dry-systems. In estimating the value of the excreta collected upon the dry-system he had, from actual observation, ascertained the proportion of the liquids and the solids retained in the tubs, and the proportion otherwise voided. He found that under similar conditions these quantities varied within very narrow limits. In some towns a small proportion of what might be considered as the chamber-slops found its way into the tubs, but 1 lb. of mixed pail-sewage, collected per head per diem, was near the truth. The value of this sewage, if it could be obtained as a concentrated manure, was undoubtedly about 16*s.* per ton, or 2*s.* 6*d.* per head per annum. But it must not be assumed, because he had found the pail-sewage to represent this value, that this sum could be realised in practice as a net profit. From this total must first be deducted the cost of collection of the pail-stuff, namely, as he had shown, 1*s.* Then the drying, manufacture, acid, and labour in preparing the concentrated manure would not fall far short of 1*s.* 3*d.* per head, leaving only a small margin of profit when all the expenses had been met. He was convinced that towns which undertook the collection of pail-sewage must not look for much in the shape of returns from the manufacture and sale of manures beyond their actual working expenses.

Mr. Shelford, in reply, expressed surprise at the remarks of Mr. Rawson, as so far from attacking the A B C process, he had shown that at Leamington it was cheaper than any other to which he had referred. He had stated that the Native Guano Company "had the settlement of the sewage question at Leamington in its hands if it sold the manure at £3 10*s.* per ton;" and again, "that the Company had actually made a market at Leamington at that price." There could be no doubt that the failure of the Crossness experiment was due to the cost of the chemicals only, for if the other expenses had been *nil*, the dry manure would still have cost £4 7*s.* 6*d.* per ton. Moreover, the sum

paid for chemicals by the Native Guano Company would have made the cost of the dry manure £3 12*s*. 6*d*. per ton before any labour was spent upon it. The invoices proved this, while the Company affected to sell manure, at a profit, at £3 10*s*. per ton. He was glad to learn that the Company was now practising at Leeds on a different principle; and if it was manufacturing a dry manure for 20*s*. per ton, as stated by Mr. Rawson, which was only two-thirds of the estimated minimum cost in the Paper, it was doing more than had yet been effected elsewhere. But unfortunately Mr. Rawson had not given that figure upon his own authority, though he had been for years acquainted with all the details of the A B C process; and Mr. Alderman Tatham's statement certainly required corroboration before it could be received as a fact. He ought perhaps to explain, in reference to the reflections made upon him personally, that he had not used any privileged information, but that all the statements in the Paper were based on documents open to the public, or for which publicity had been sought.

The opinion entertained by Dr. Voelcker, as to the costliness of disposing of sewage matters, founded upon experience in Belgium and Prussia, failed to show how far the cost there was due to land carriage, and to the amount of moisture in the sewage matters. This affected the cost materially, and no fair comparison could be made without reducing each manure to its value when dry. He had made some experiments to determine the quantity of moisture in sewage sludge, and he found that, when solid enough to shovel, it contained 80 per cent. of moisture, but was quite liquid when it contained 85 per cent. or more. Any sewage matter containing 90 per cent. of moisture would yield only 10 per cent. of dry manure, which, at the high estimate of 150*s*. per ton, would make the matter containing it worth only 15*s*. per ton. The solid sewage matter would yield only 20 per cent. of dry manure, and therefore would not be worth more than 30*s*. per ton. But if from these amounts the minimum cost of collection were deducted, given by Mr. Fowler as 12*s*. 3*d*. per ton at Leeds, and a similar amount were deducted for cost of distribution, sale, &c., there would be a loss on the liquid matter, and a possible profit of 5*s*. 6*d*. per ton on the solid matter. Hence the amount of moisture was an important element in the question. It had been stated by Mr. Melliss that the cost of treating the sewage of Coventry was 1*s*. 7*d*. per head per annum, which, if it referred to the conversion of all the sewage into a dry manure, would be nearly the minimum cost given in the Paper; but he believed that a great part of the sludge at Coventry was not dried. If all the sludge were dried the cost

would be more than 1*s.* 7*d.* per head; but the process was nevertheless a cheap one, on account of the small quantity and low price of the chemicals, and the excellent arrangement of the works. He was not responsible for the information given in the Appendix to his Paper, which had been so severely criticised, and had been defended by Mr. Meyerstein, who had supplied it, and who had stated his authority for adopting such high values.

In conclusion, he would endeavour to sum up the scope and purpose of his Paper, which had been slightly misapprehended by some speakers. His object had been to describe the present position of precipitation as a practical means of settling the sewage question, and he thought that such a description would be incomplete without an account of the work done by the Native Guano Company, in the first place, at Leamington, with a small quantity of chemicals, and afterwards at other places with larger quantities, until at Crossness the cost and quantity of the chemicals employed brought about an exemplary failure Speaking generally, he thought that precipitation processes might be classed under two heads—cheap precipitation, and recuperative precipitation.

Cheap precipitation included the lime process, the A B C process as now practised at Leeds, Dr. Anderson's process, and others; and in favour of this class the most that could be said was that the necessary loss in working might eventually be reduced to a minimum of 6½*d.* per head per annum. In precipitation everything depended upon the value obtainable for the manure, and in this lay all the difficulty at the present time, partly because of the difference among chemists upon it, and partly because of the popular prejudice against sewage manures. Mr. Redgrave had stated that concentrated manures were sold at prices approximating to their theoretical value, while feeble manures rarely fetched more than from one-fourth to one-tenth of that value. This seemed to be admitted in the discussion; and he had been informed, by persons acquainted with the trade, that a manure which sold for less than £4 per ton was practicably unmarketable. If that were so, cheap precipitation could only be carried on at a loss, and however useful it might be as a palliative, it could never become a permanent solution of the sewage question.

Recuperative precipitation included the Phosphate Sewage, and the processes of Mr. Dugald Campbell and Mr. Whitthread, the two last of which had been referred to in detail in the Paper as the most recent examples of the class, and not as processes which he advocated. To them the value of the manures produced was vital, but it seemed as yet impossible to obtain the facts from

chemists, for on one side the precipitated phosphates had been valued at 2*s.* 3*d.* per unit, and on the other side the higher price of 3*s.* 3*d.* per unit.

Whatever the values of the constituents of a manure, they became more important in proportion as the manure was either fortified or concentrated, and until they were settled, both by chemists and agriculturists, there could be no permanent solution of the sewage problem by precipitation, even where precipitation was applicable. Meanwhile there was a dead lock, and progress was impossible unless the town authorities made up their minds to pay part of the cost. For this purpose he had given sufficient information to enable them to determine what sum they could safely pay, and had suggested £2 2*s.* 10*d.* per million gallons of sewage. He thought that, small as that sum was, it would suffice to stimulate the latent energy of private enterprise, leading to the removal of the difficulty in many places adapted to precipitation, and eventually, he hoped, to a permanent solution of the sewage question. But in this country it was customary to go by steps, and the next step was that the towns must pay.

April 4 and 11, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

The discussion upon the Papers, No. 1,474, on "Sewage Interception Systems, or Dry-Sewage Processes," by Mr. Gilbert Richard Redgrave, and No. 1,475, "The Treatment of Sewage by Precipitation," by Mr. William Shelford, occupied the whole of both these evenings.

The following Candidates were balloted for and duly elected on the 4th of April:—James Ramsay, as a Member; Charles Sneath Allott, Rodolfo de Arteaga, Stud. Inst. C.E., Henry Stracey Barron, Charles James Bowstead, Alfred Davidson, Thomas Wilberforce Davies, Daniel Earnshaw, Norman Garrard, Charles Currie Gregory, Francis Augustus Heath, Thomas Jefferies, John Mackenzie, John O'Connell, Benjamin Langford Forster Potts, Colonel John Davenport Shakespear, Oswald Turner, Robert Edward Wilson, and Thomas Percival Wilson, as Associates.

At the same meeting it was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred Richard Hammersley Heenan, Leonard Robert Roberts, and Christopher Thwaites from the class of Associate to that of Member.

Also that, under the provisions of Sect. IV. of the Bye-Laws, the following Candidates, having been duly recommended, had been admitted as Students of the Institution:—Roderick Walter Baynes, William Alfred Benson, Robert Charles Brebner, Charles James Grierson, George Richard Gwyn, John Blackley Little, Thomas Joseph Myles, Sydney Prestije, Edward Quick, Henry John Saunders, Charles Henry Shortt, James Robert Tickell, Carleton Fowel Tufnell, and Walter Clifford Tyndale.

On the 11th of April it was resolved to adjourn for a fortnight, in order to avoid holding a meeting on the evening of Easter Tuesday, April the 18th.

Sect. II.—OTHER SELECTED PAPERS.

No. 1,478.—"On the Percolation of the Rainfall on Absorbent Soils." By John Evans, F.R.S., Assoc. Inst. C.E.

The following communication is intended as a supplement to the remarks of the Author during the discussion of Mr. Frederick Braithwaite's Paper "On the Rise and Fall of the River Wandle," which was read at the meeting of this Institution on the 22nd of January, 1861.[1]

On that occasion the Author presented Tables embodying the register of the observations of "Dalton gauges" which had been kept by his late partner, Mr. J. Dickinson, and himself, at Nash Mills, near Hemel Hempstead, Herts, for a period of about twenty-five years. A portion of these Tables had already been brought under the notice of the Institution in 1843 and 1850.[2] It is proposed on the present occasion to limit the Tables to the last fifteen years, although in discussing their results it may be desirable to cite the records of the last twenty years, so as to obtain a wider basis for generalisation.

The gauges are the same as formerly described, and their contents have not been disturbed since they were first in use. They consist of two cast-iron cylinders, 18 inches in diameter and 3 feet in length, turned to a knife-edge at the top, and sunk to a depth of 3 feet below the level of the ground in which they are placed, so that the edge just projects. One of the cylinders is filled with the ordinary surface soil of the neighbourhood, and the other with fragmentary upper chalk. Grass is growing on the upper surface of the contents of the gauges, and also on the ground surrounding the cylinders. The rainfall is observed in the immediate neighbourhood of the percolation gauges, and the register is made up at 9 A.M.

The winter half-year is considered to commence on the 1st of October, and the summer half-year on the 1st of April.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 219.
[2] *Ibid.*, vol. ii., 1843, p. 160; and vol. ix., p. 158.

TABLE I.—RAINFALL and PERCOLATION through DALTON GAUGES.

	1860–61.			1861–62.			1862–63.			1863–64.			1864–65.		
	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Oct. .	1·65	0·62	0·75	1·25	..	..	3·68	..	0·50	1·87	..	0·30	1·12	..	..
Nov. .	2·70	2·30	2·30	3·36	2·25	2·20	1·15	..	0·78	1·80	..	1·68	2·60	..	..
Dec. .	2·40	1·26	1·12	1·40	0·35	0·80	1·62	0·88	1·25	1·13	0·65	0·65	0·38	..	..
Jan. .	0·50	0·98	0·95	2·18	1·50	1·48	3·34	2·33	2·60	1·09	0·52	0·68	3·68	..	0·65
Feb. .	2·00	1·70	1·73	0·40	0·45	0·41	0·47	0·35	0·37	1·01	0·42	0·54	2·03	2·82	2·40
Mar. .	2·31	0·75	0·70	4·04	2·87	3·30	0·75	..	..	2·34	1·59	2·01	1·12	0·60	0·50
	11·56	7·61	7·55	12·63	7·42	8·19	11·01	3·56	5·50	9·24	3·18	5·89	10·93	3·42	3·55
Apr. .	0·80	..	..	2·52	1·52	1·52	0·77	..	..	1·00	0·35	0·45	0·26	..	..
May .	0·91	..	..	3·18	0·87	0·25	1·07	..	..	2·25	..	..	2·21	..	..
June .	2·45	..	..	2·20	..	..	4·32	..	0·19	1·20	..	..	2·50	..	..
July .	3·92	0·70	0·61	1·63	..	..	0·85	..	..	0·46	..	..	2·15	..	..
Aug. .	0·55	..	..	2·33	..	..	2·99	..	..	0·59	..	..	4·89	..	..
Sept. .	1·75	0·43	0·41	2·51	..	..	3·40	..	..	2·92	..	..	0·59	..	..
Summer	10·38	1·13	1·02	14·37	2·39	1·77	13·40	..	0·19	8·42	0·35	0·45	12·60	..	..
Winter .	11·56	7·61	7·55	12·63	7·42	8·19	11·01	3·56	5·50	9·24	3·18	5·89	10·93	3·42	3·55
Total .	21·94	8·74	8·57	27·00	9·81	9·96	24·41	3·56	5·69	17·66	3·53	6·34	23·53	3·42	3·55

TABLE I.—RAINFALL and PERCOLATION through DALTON GAUGES—*continued.*

—	1865–66.			1866–67.			1867–68.			1868–69.			1869–70.		
	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Oct. . .	6·57	0·60	1·02	1·06	..	..	2·02	..	..	2·90	..	..	1·33	..	..
Nov. .	2·53	2·15	2·36	2·03	..	..	0·68	..	..	1·66	..	..	2·23	..	0·20
Dec. .	1·72	0·97	0·99	2·35	0·97	1·07	1·61	..	0·34	5·67	2·68	4·68	3·96	0·85	3·20
Jan. .	4·02	3·68	4·02	3·30	1·80	2·76	3·78	1·28	3·60	3·41	2·75	3·15	1·27	1·08	1·68
Feb. .	3·34	2·27	2·54	1·57	1·07	1·50	1·70	0·35	0·42	2·23	1·70	2·18	2·48	1·82	2·28
Mar. .	1·82	0·80	1·12	2·29	0·80	1·64	1·57	0·40	1·00	1·71	0·51	1·20	2·06	0·75	1·40
	20·00	10·47	12·05	12·60	4·64	6·97	11·36	2·03	5·36	17·58	7·64	11·21	13·33	4·50	8·76
Apr. .	1·79	0·03	0·20	2·27	..	0·32	1·88	..	0·22	1·93	0·02	0·74	0·34	..	..
May . .	1·75	..	..	3·16	0·18	0·93	0·85	..	..	3·53	..	1·20	1·17	..	..
June .	3·50	..	..	1·07	..	0·14	0·55	..	..	1·00	..	0·06	0·80	..	..
July. .	1·63	..	..	4·12	..	..	0·39	..	..	1·03	..	..	1·26	..	..
Aug. .	2·62	..	..	1·90	..	..	3·89	0·04	0·20	1·67	..	..	2·00	..	..
Sept. .	4·30	..	..	1·85	..	..	2·49	..	..	3·64	..	..	2·02	..	..
Summer	15·59	0·03	0·20	14·37	0·18	1·39	10·05	0·04	0·42	12·80	0·02	2·00	7·59	..	..
Winter .	20·00	10·47	12·05	12·60	4·64	6·97	11·36	2·03	5·36	17·58	7·64	11·21	13·33	4·50	8·76
Total .	35·59	10·50	12·25	26·97	4·82	8·36	21·41	2·07	5·78	30·38	7·66	13·21	20·92	4·50	8·76

—	1870–71.			1871–72.			1872–73.			1873–74.			1874–75.		
Oct. .	3·90	..	..	1·24	..	1·18	4·66	..	1·00	2·58	..	..	2·60	..	..
Nov. .	1·44	..	..	0·66	..	0·32	4·25	1·62	3·51	1·74	..	1·08	2·09	..	..
Dec. .	2·90	0·72	2·22	1·20	..	0·86	4·78	4·04	4·64	0·52	..	..	2·16	0·85	1·10
Jan. .	1·37	..	..	4·76	3·50	4·68	3·94	3·36	3·85	1·90	0·78	1·82	3·13	2·40	3·12
Feb. .	1·51	1·36	2·46	1·46	0·45	1·16	1·89	0·88	1·30	1·71	0·90	1·30	1·03	0·60	0·95
Mar. .	1·42	..	0·67	1·93	0·70	1·30	2·03	1·35	1·75	0·46	0·18	0·20	0·68	0·30	0·40
	12·54	2·08	5·35	11·25	4·65	9·50	21·55	11·25	16·05	8·91	1·86	4·40	11·69	4·15	5·57
Apr. .	2·94	..	0·70	1 ·87	0·34	0·85	0·76	..	..	2·01	0·05	0·65	1·48	..	0·37
May. .	0·91	..	0·10	3·11	0·66	1·40	2·08	..	..	1·32	..	..	2·11	..	0·37
June .	3·16	..	..	3·17	..	0·45	1·89	..	..	1·23	..	..	2·35	..	..
July. .	3·02	..	0·92	2·91	..	..	2·27	..	..	1·25	..	..	5·58	..	2·72
Aug. .	0·76	..	..	2·13	..	..	1·49	..	..	1·64	..	..	1·25	..	..
Sept. .	5·30	..	..	1·25	..	..	2·80	..	..	3·26	..	..	2·23	..	..
Summer.	16·09	..	1·72	14·44	1·00	2·70	11·29	..	..	10·71	0·05	0·65	15·00	..	3·46
Winter .	12·54	2·08	5·35	11·25	4·65	9·50	21·55	11·25	16·05	8·91	1·86	4·40	11·69	4·15	5·57
Total.	28·63	2·08	7·07	25·69	5·65	12·20	32·84	11·25	16·05	19·62	1·91	5·05	26·69	4·15	9·03

TABLE II.

—	Winter.			Summer.			Number of Wet Days in Winter.	Number of Days on which more than 0·5 in. fell.
	Rain.	Soil.	Chalk.	Rain.	Soil.	Chalk.		
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.		
1855–6	14·48	6·82	10·47	14·86	2·79	3·09	76	9
1856–7	11·96	3·72	7·19	14·11	1·11	1·32	71	3
1857–8	11·81	5·64	7·16	12·27	0·80	0·84	63	5
1858–9	9·64	0·09	2·69	18·31	..	4·22	71	1
1859–60	16·49	9·27	12·44	20·40	3·16	8·94	93	4
1860–1	11·56	7·61	7·55	10·38	1·13	1·02	81	3
1861–2	12·63	7·42	8·19	14·37	2·39	1·77	79	6
1862–3	11·01	3·56	5·50	13·40	..	0·19	82	4
1863–4	9·24	3·18	5·89	8·42	0·35	0·45	77	2
1864–5	10·93	3·42	3·55	12·60	..	..	73	4
1865–6	20·00	10·47	12·05	15·59	0·03	0·20	113	7
1866–7	12·60	4·64	6·97	14·37	0·18	1·39	100	4
1867–8	11·36	2·03	5·36	10·05	0·04	0·42	90	3
1868–9	17·58	7·64	11·21	12·80	0·02	2·00	104	7
1869–70	13·33	4·50	8·76	7·59	..	..	88	6
1870–1	12·54	2·08	5·35	16·09	..	1·72	83	1
1871–2	11·25	4·65	9·50	14·44	1·00	2·70	85	3
1872–3	21·55	11·25	16·05	11·29	..	..	108	7
1873–4	8·91	1·86	4·40	10·71	0·05	0·65	73	2
1874–5	11·69	4·15	5·57	15·00	..	3·46	87	3
	260·56	104·00	155·85	267·05	13·05	34·38	1,697	84
Average of 20 years	13·028	5·200	7·792	13·352	0·652	1·719	..	..
	Annual average . . .			26·380	5·852	9·511	85	4
The annual average rainfall of the seven years ending the 30th of September, 1860, was				26·492	5·751	9·872	..	..

It will be observed that the annual rainfall appears to be somewhat in excess of that which is recorded by Mr. Greaves, which for the twenty-two years ending December 1873 is stated to have been 25·837 inches. If, however, the eighteen years ending the 30th of September, 1873, be taken, and the rainfall as recorded by Mr. Greaves be divided into winter and summer half-years, as in the foregoing tables, it will be found that the average is, winter, 13·319 inches, summer, 12·702 inches, giving a total of 26·021 inches. The winter rainfall at Lee Bridge seems, therefore, to have been rather greater than that at Nash Mills. This circumstance might lead to a somewhat greater amount of percolation, but is not sufficient to account for the difference between an annual average for twenty-two years of 6·866 inches of percolation at Lee

Bridge, and one of 5·852 inches at Nash Mills. It is probably due to some difference in the character of the soil with which the respective gauges are filled, or to the underdrainage of the soil in the gauge being more effective in one than in the other, so that the rainfall has practically in one case rather less thickness of soil through which to percolate before passing to the receiver than in the other.

The different capacities of different soils for the downwards transmission of water is well exemplified by a comparison of the results of the gauges filled with soil and chalk respectively, the soil allowing of a passage of 5·852 inches only as against 9·421 inches through chalk. Looking, however, at the power of capillary attraction inherent in chalk, so well exemplified by an experiment of Professor Ansted, it may be doubted whether a gauge only 3 feet in depth affords a fair test for the quantity of the rainfall which, in districts where the chalk comes to the surface, finds its way down to the subterranean reservoir to feed chalk-springs. It is in fact a question whether water which has reached a distance of even 10 feet from the surface has got entirely beyond all atmospheric influences, and may not again be drawn up within the limits of superficial evaporation. Even with a depth of 3 feet there are a few exceptional periods in which the percolation through the chalk gauge has been somewhat less than through that filled with soil, though owing to the different speed at which the water descends in the two cases, and to the tables being made up at the end of each month, sometimes in the midst of rain continuing over several days, it is difficult to draw exact conclusions.

It will be observed that there are great variations in the amount of rainfall both during the winter and the summer half-years. The maximum winter rainfall was in 1872–73, when it amounted to 21·55 inches at Nash Mills, and to 20·332 inches at Lee Bridge; the minimum was in 1873–74, when it was only 8·91 inches at the former place. The maximum fall during the summer months was in 1860, when it was 20·40 inches at Nash Mills, and 19·832 inches at Lee Bridge. The minimum was in 1870, when the fall at the two places was 7·59 inches, and 6·958 inches respectively.

Great as are these variations, they are as nothing when compared with the variations in the amount of percolation, which during the winter half-year ranged at Nash Mills from 11·25 inches iu 1872–73, down to 1·86 inch in 1873–74, or going back beyond fifteen years to 0·09 inch in 1858–59. The maximum winter percolation at Lee Bridge was 12·437 inches in 1865-66, and the minimum in 1858–59, when it was only 0·900 inch. During the summer half-

year the percolation was in general insignificant or none, the exceptions being generally due to a continuance of the spring rains in unusual quantity through April, May, and June. It is worthy of notice that in 1871, with a summer rainfall of 16·09 inches, there was no percolation at Nash Mills; and at Lee Bridge, with 14·978 inches of rain, only 0·450 inch found its way through the gauge. In 1873, with a fall of 11·937 inches, there was no percolation at that place. The statistics for Nash Mills are those of the soil gauge, not of the chalk.

Although it seems almost impossible to trace all the causes which have conduced to increase or to diminish the amount of percolation in any given years, it may be of interest to compare the meteorological history of two years in which, with the rainfall above the average, the percolation has in the one case been far above the normal amount, and in the other far below it. For this purpose the years 1861–62 and 1870–71 seem well adapted.

The register of the two years is as follows:—

	Rain. Inches.	Soil. Inches.	Chalk. Inches.
1861–62.—Winter	12·63	7·42	8·19
„ Summer	14·37	2·39	1·77
Total	27·00	9·81	9·96
1870–71.—Winter	12·54	2·08	5·35
„ Summer	16·09	..	1·72
Total	28·63	2·08	7·07

Taking the former year, the rain which had fallen in the previous September had sufficed to saturate the soil in the gauge and cause some percolation. In October 1·25 inch of rain fell, sufficing to keep the ground moist. During the first twelve days of November upwards of 1 inch of rain fell, and on the 13th and 14th 1·47 inch, which was followed by frosts and rains, making up a total of 3·36 inches for the month. The 1·40 inch of rain for December all fell in the first fifteen days, and percolation ceased on the 24th. In January there were seventeen wet days with a fall of 2·18 inches, and a percolation of 1·50 inch; to this must be added 0·32 inch, which went through the gauge during the dry weather at the beginning of February. A subsequent fall of 0·40 inch produced a percolation of 0·13 inch. In March there were no less than twenty-three wet days, with the large rainfall of 4·04 inches. This was followed by thirteen wet days in April and fifteen in May, with falls of 2·52 inches and 3·18 inches respectively, thus causing an exceptional percolation during the early part of the

summer months. The four remaining months produced no percolation either through soil or chalk.

Turning to 1870–71, the preceding summer was remarkably dry, only 7·59 inches of rain having fallen during the six months. The 3·90 inches which fell in October was insufficient to saturate the soil. Only 0·03 inch of rain fell during the first eleven days of November, so that evaporation went on under the influence of a north-east wind; and from the 24th of November to the 3rd of December no rain fell. From that day, however, until the 19th, there were thirteen wet days, with a fall of 2·75 inches of rain, producing, with 0·15 inch which fell at the end of the month, 0·72 inch in the soil gauge. Only 1·37 inch fell in the month of January, and never more than 0·18 inch on any one day, and then separated by an interval of fine weather from previous or subsequent rain. By the end of the month, however, the soil became saturated, and eight days out of the first twelve in February having been wet with a fall of 1·27 inch, 1·20 inch percolated, and 0·16 inch more followed in the course of the next few days. The rainfall in March was only 1·42 inch, as against 4·04 inches in 1862; and a wet April, with a fall of 2·94 inches, produced no percolation through soil; nor did the rainfall of the five following months, though that in September amounted to 5·30 inches.

It is thus apparent that the amount of percolation is more dependent upon the time at which the rain falls, and the manner in which it is distributed, than on its actual amount, and that the only means for forming an approximate estimate of the proportion of the rainfall consists in the use of gauges such as those employed by Mr. Greaves and by the late Mr. Dickinson. It is therefore in the highest degree desirable that such observations should be extended, both by means of gauges filled with different varieties of earths, and also of different depths, so as to ascertain if possible the depth at which water gravitating into the earth may be considered as beyond the reach of all superficial influences.

Appended to Table II. are columns showing the number of days on which rain fell during the winter half-years, and also of those in the same period on which the fall was to the extent of 0·5 inch or more. Although, as before observed, it seems impossible to give any formula by which the percolation in any period might be ascertained without gauging, there is a general correspondence between the number of inches percolating through the soil and the number of days on which 0·5 inch of rain fell. This is the more apparent when allowance is made for the number of wet days being above or below the average.

As a means of testing, on a large scale, the accordance of such results as those afforded by Dalton gauges with the operations of nature, the constant gauging of streams, the gathering ground of which consists entirely of some pervious rock, has been recommended. It must, however, be remembered that such tracts of country are hard to find, as even in chalk districts the hills are often covered with more or less impervious drift, and the lower chalk is much more impervious than the upper chalk. There is, moreover, great difficulty in estimating the exact area of the gathering ground in each case, as the line of what may be termed the subterranean watershed, that is to say, the line along the summit of the subterranean hill of water piled up within the body of the chalk, is unconnected with the watershed of the surface, and must, in many, if not in most instances, vary in position from it. The surface of the subterranean reservoir from which the springs along valleys in the chalk are fed is, as is well known, inclined at gradients varying from 10 or 12 feet in the mile to upwards of 40 feet, and the position of the summit will depend partly on the levels of the two points of delivery between which it is placed, and partly on the permeability of the rock on either side, or its "angle of friction." Pending further inquiries it is however, needless to enter more fully into this question.

No. 1,477.—"Hydraulic Apparatus for Loading Minerals from Railway Wagons into Ships." By WILLIAM HENRY THOMAS, M. Inst. C.E.

IN carrying out the works of the Cornwall Minerals railway, a system of railways on the gauge of 4 feet 8½ inches, designed to bring iron ores from the mines of the "Great Perran Lode" to the Port of Fowey, arrangements had to be made for the shipment of 2,000 tons daily at the latter place, where a natural harbour of considerable extent is available for vessels drawing 20 feet of water and upwards, with a rise and fall at spring tides of from 19 feet to 22 feet.

The railway at its termination at Fowey skirts the shore, being partially excavated in the face of the cliff, which consists of clay slate, or killas, and partially carried on an embankment, the slope of which runs down to from 12 feet to 14 feet below low-water mark. The formation-level of the line is 15 feet above high-water spring tides. The bottom being generally good, the material of the bank was tipped, and allowed to assume a slope of about 1½ to 1, at which it stood well. Three jetties of timber were run out at right angles to the line of rails, to such a distance as would command a minimum depth of 18 feet at low water for vessels lying alongside. (Plate 7, Figs. 1 and 2.) They were constructed for a double line of way, and connected to the main line by turn-tables, the distance being too short to allow of a junction by curves and points.

The rolling stock, designed especially for the iron-ore traffic, consisted of wagons with a wheel base of 6 feet 6 inches, the wheels being 3 feet in diameter. The framing was of oak; the bodies, 11 feet long, 6 feet 9 inches wide, and 2 feet 6 inches deep, were of wrought iron, their weight being 4 tons 16 cwt. each, and their capacity sufficient to accommodate 12 tons, for which weight the wheels, axles, and springs were calculated. The doors were at the end, and overhung from the top of the wagons, with the ordinary catches at the bottom, and the sides arranged for end-tipping. To do this with the greatest expedition, and at the least cost, both as regarded original outlay and expense of working, were the requirements which had to be kept in view.

At the jetty head, which was recessed to receive it, a wrought-iron tipping frame (Plate 7, Fig. 5), 12 feet long and 5 feet 6 inches

wide, was pivoted on an axle at its centre, and this fram capable of tipping outwards to an angle of 30°. At the end this frame was connected by a link to the ram of an hyd press, constructed on the "Trunk" system for compactness. the bottom of this press, which had an effective diameter of 12 i a feed-pipe 3 inches in diameter, provided with a stop valv to a tank with a capacity of 150 gallons, fixed on the high g at the back of the railway, at about 50 feet above rail-level. permanent rails were laid on the upper surface of the fram outer ends being turned up at such a distance as would of the wagons being run out until the leading wheels stood in front of the axis of the frame, the back wheels being c quently only 2 feet 6 inches behind it, and thus creating a tend to tip the frame. A counterpoise, hung from below the frame, connected by chains and adjusting screws to the back, an means of these screws the position of the counterpoise cou varied, if necessary, to suit different loads, its normal position b fixed to accommodate loads of 12 tons (Figs. 6 and 7).

The *modus operandi* is as follows:—The valve of the being closed, a wagon is run up till its leading wheels are against the turned-up ends of the rails, the tendency of the w and frame to tip being counteracted by the water in the p On the valve being opened, the frame, with the wagon, f and the load is tipped down a shoot into the vessel awaitin The weight of the loaded wagon, producing a pressure of a 110 lbs. on the square inch in the press, forces the water up into tank, and when the plunger has arrived at the bottom of its str the valve is closed. To raise the empty wagon, a force of 17 per square inch is required, and this is amply provided by the h of 55 feet in the tank; so that on the valve being opened ag the frame and wagon rise to their original position. It stipulated that the tipping apparatus should enable ten wagon be tipped in one hour, but the Author has seen nineteen wag tipped with ease in fifty-nine minutes.

The general arrangement and details differ little from hydraulic machinery to be seen at many ports, except in particular, which the Author believes to be novel, and which thinks may be well adopted in similar cases, viz., that instea the accumulator, engine and pumps, &c., usually employed— expense of which in first cost and working is considerable— loaded wagon in descending pumps up the water and produces power necessary for raising it when empty.

The whole operation is under perfect control, and the wa

NERY
ME.

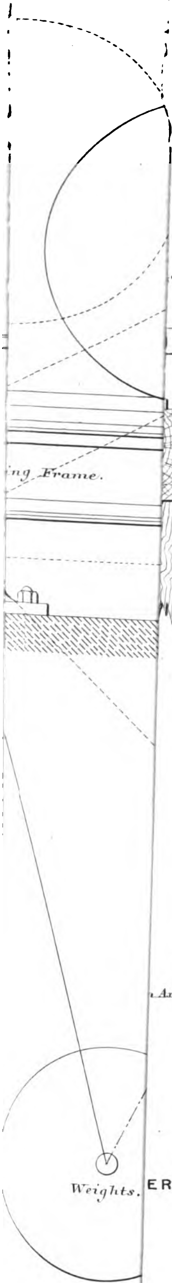
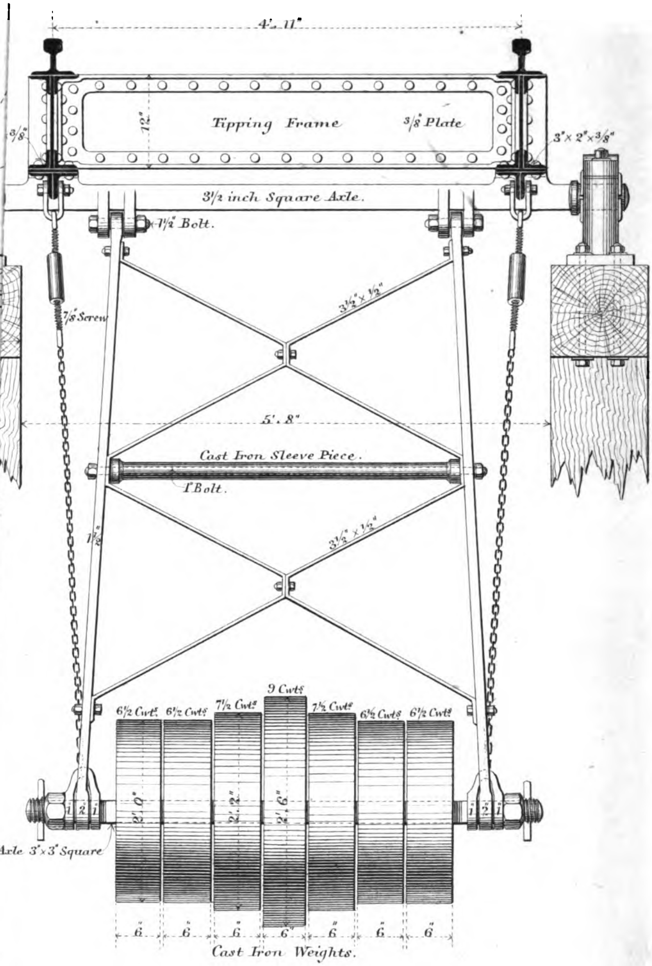


Fig: 7.



SECTIONAL ELEVATION.

ERPOISE.

TIP WAGON F

ame tipped.

THOS KELL, LITH 40, KING ST COV

may be lowered instantly, or as slowly as desired. The small amount of leakage and waste is provided for by a small hydraulic ram, which keeps the tanks full, and at the same time supplies the tank for watering the locomotive engines.

Figs. 3 and 4 represent the forces exerted by the loaded and unloaded wagon.

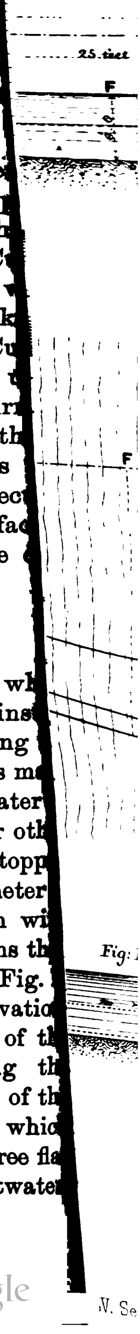
The communication is accompanied by a series of drawings, from which Plate 7 has been compiled.

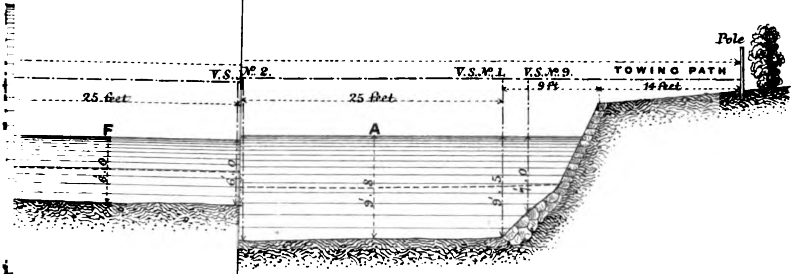
No. 1,481.—" On a Current Meter, a Deep-sea Current In
and an Improved Ship's Log." By BENJAMIN THE
MOORE, M.A., C.E.

THIS Paper contains an account of three new instrume
Current Meter, a Deep-sea Current Indicator, and an Im
Ship's Log. They are all constructed upon the same mech
principle, and have many features in common. The C
Meter was designed to measure the velocity of running
with a degree of accuracy not attainable by any other k
means, and at the same time to do this rapidly. The Cu
Indicator is introduced in the belief that it will prove a
instrument in ascertaining the direction of marine cur
especially of deep-sea currents; and, in combination with
Deep-sea Current Meter, of determining their velocity as
as their direction. The Improved Ship's Log, by its pec
construction, travels at a uniform depth below the surfa
the water, and with remarkable steadiness, keeping a true
reckoning.

THE CURRENT METER.

The two main features of this instrument are the frame, wh
is so constructed as to secure the required position of the ins
ment in running water; and the rotating cylinder, containing
internal mechanism for recording the number of revolutions m
in a given time. The instrument can be lowered into water
the required depth by a light chain or cord from a boat or oth
platform, and the rotating cylinder can be set in action or stopp
at any instant while under water. When the current meter
lowered into running water it takes up a definite position wi
respect to the direction of the stream, and steadily maintains th
position, no apparatus being required to fix it. In Plate 8, Fig.
is a side elevation of the instrument, and Fig. 2 a front elevatio
Fig. 3 is a vertical longitudinal section, and Fig. 4 a plan of th
frame with a section of the revolving cylinder, showing th
mechanism within it. Figs. 5 and 6 are transverse sections of th
revolving cylinder, and Fig. 7 shows the suspended frame whic
contains the mechanism. The frame consists mainly of three fla
thin bars of brass, united to the solid ogival head, or cutwate





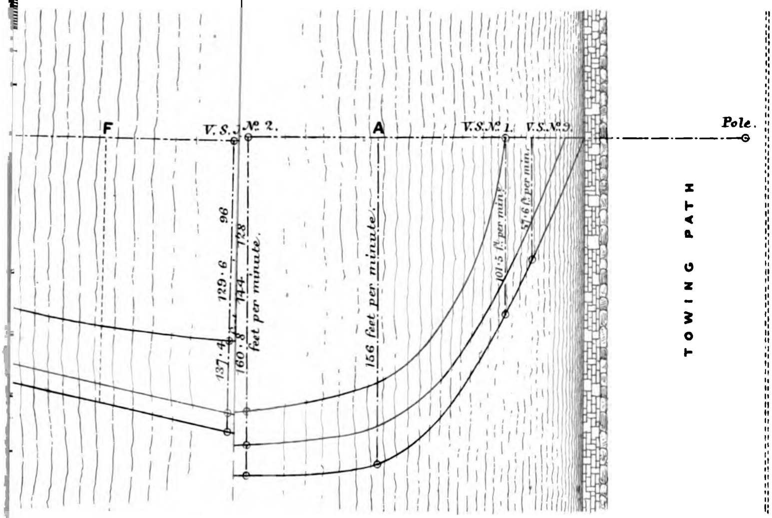


Fig: 10.

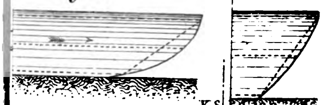
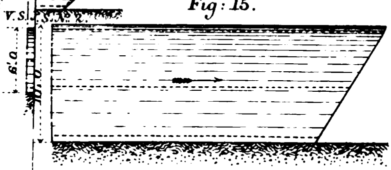


Fig: 15.

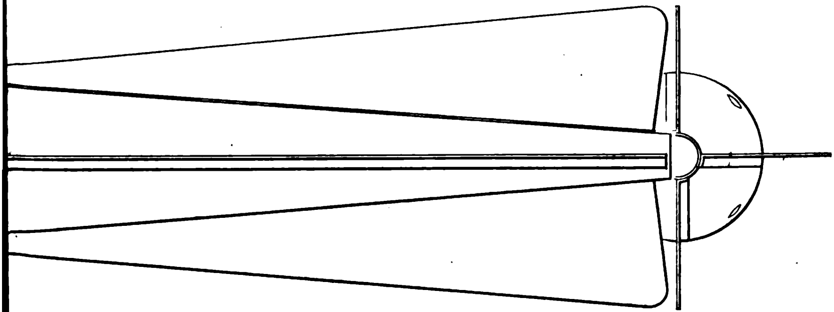


THOS KELL, LITH. 40, KING ST COVENT GAR


SEA
POSITI

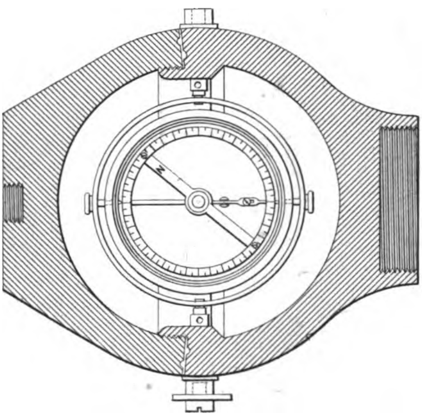
SEA CURRENT INDICATOR.

Fig: 7.



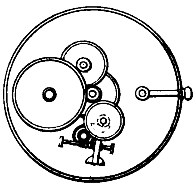
POSITION OF THE INSTRUMENT IN A STRONG CURRENT.

Fig: 9.



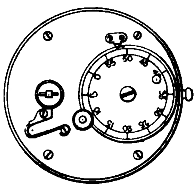
HORIZONTAL SECTION OF CASE WITH PLAN
of Suspended Box and Compass.

Fig: 10.



PLAN OF TRAIN OF WHEELS
in Lower Part of Suspended Box

Fig: 11.



PLAN OF UNDERSIDE,
of Suspended Box.

THOS. KELL, LITH. 40, KING ST. COVENT GARDEN

which forms the front of the instrument, and terminating in a long double tail or rudder, the section of which is a cross with equal arms. They are bound together, to form a stiff and strong frame, but so as to offer the least possible resistance to running water.

The frame is suspended from a stirrup by two bearings, the geometrical axis of which is perpendicular to the longitudinal axis of the frame, viz., that which passes through the point of the ogival head and the line of intersection of the plates of the double tail; and the sides of this stirrup are extended downwards, and pierced with two holes for the purpose of attaching a lead weight to keep the instrument in place when used in a rapid stream.

The rotating cylinder is immediately behind the ogival head, having its axis coincident with the longitudinal axis of the frame. The centre of gravity of the whole instrument is in the geometrical axis of the bearings by which the instrument is suspended from the stirrup, and midway between them.

The instrument is symmetrical about a vertical plane through the longitudinal axis, and (with the exception of the keel plate) about a horizontal plane through the same axis. Thus, when the current meter is lowered into running water by a cord attached to the swivel at the top of the stirrup, the stream, acting upon the double rudder, will bring the longitudinal axis of the instrument in the direction of the current, with the ogival head pointing accurately up the stream, and this position of the instrument will hold good however great may be the velocity of the stream; for the vertical line through the centre of gravity, the direction of the pull upon the stirrup, and the resultant pressure of the running water upon the instrument, all pass through one point, and are in equilibrium, and consequently no couple is brought into action to turn the instrument out of the required position.

This does not take into account the action of the water on the keel plate, which produces a couple of small moment tending to raise the tail of the instrument; but this tendency is easily corrected by giving a slight inclination upwards to the horizontal plate of the tail, which calls into action a couple of equal moment in the opposite direction, and thus the axis of the instrument is kept in the direction of the stream.

The cylinder is set in rotation, or stopped, by operating on the spring which is fixed to the frame and partly embraces the cylinder. A light cord attached to the spring passes side by side with the cord which suspends the instrument to the hand of the operator;

by raising the cord a few inches, until it is tight, the spring is lifted and the cylinder is released, and when the cord is let go the spring is set free and again engages the cylinder. It is convenient to pass this cord through small rings upon the main cord at intervals of 1 foot; thus all chance of the stream lifting the spring is avoided, and the rings serve to measure the depth to which the instrument is lowered. The cylinder is set in motion, when free, by the action of the running water on the screw blades fixed to it.

In the instrument shown in Plate 8, the recording mechanism is placed inside the rotating cylinder, which is water-tight and contains a strip of glass so placed that the mechanism can be clearly seen through it. In other instruments the mechanism is enclosed within a water-tight tube of glass which slides in and out of the rotating cylinder; this construction is shown in Plate 9, Figs. 1, 2, and 3, illustrative of "Ships' Logs." The tube is closed by two brass discs connected together by a thin steel spindle, the axis of which coincides with that of the tube and cylinder; this spindle is screwed at its ends into the discs, by which means they are drawn close to the ends of the glass tube, and the joints are made water-tight by thin rings of leather. When the cylinder containing the glass tube is set in rotation, the small steel spindle also revolves about its own axis. From this spindle is suspended a small rectangular brass frame having holes at the ends through which the spindle passes. The frame contains a simple train of wheels connected by a worm-wheel with an endless screw upon the spindle, the centre of gravity of the frame and wheels being below the axis of the spindle; consequently, when the spindle revolves the frame remains at rest, or oscillates very slightly, and motion is set up in the train of wheels, and the revolutions of the cylinder are recorded by graduated dials revolving with the wheels. There is no stuffing-box, stiff joint, or bearing, in any part of the instrument. The resistances of the working parts are extremely small, and the cylinder may be made to revolve with a velocity much greater than that due to any running water without fear of the suspended frame tripping, or turning over. The rotating cylinder being hollow and water-tight in some instruments, and containing a water-tight glass tube in others, is supported by the water to the extent of the weight of the water displaced, the difference between its weight in water and in air being the weight upon the bearings. This resulting weight is less than 1 oz. in some of the lighter instruments, and in the heavier instruments, containing the glass tube, it gives an average pressure

on each bearing of about 5 oz.; and as the bearings are less than $\frac{1}{16}$ inch in diameter, the frictional resistance which they offer to the motion of the cylinder is extremely small. Moreover, the instrument is far more sensitive to the action of running water than would at first appear, because the weight of the rotating cylinder and its contents is twice as great in air as in water, being on an average 10 oz. in water and 21 oz. in air.

The friction of the internal mechanism within the glass cylinder is constant and wholly unaffected by the velocity of the stream. This mechanism is lubricated by oil, which seldom requires to be renewed.

The friction on the front external bearing is also constant, as this bearing only supports one end of the cylinder and sustains no thrust; the weight upon it is about 6 oz. The friction on the back bearing, which also acts as a pivot, is the only variable friction in any working part. This pivot has to sustain the thrust caused by the action of the running water on the screw blades only, there being no thrust due to the running water on the front end of the cylinder, because that is protected by the solid ogival head which forms the front of the frame. Thus the only variable friction is that due to the pressure on the back pivot. The moment of the resistance due to this friction is proportional to the product of the pressure and the radius of the pivot. This radius being less than $\frac{1}{32}$ inch, while the effective radius of the screw blades is not far short of 2 inches, the ratio which this moment of resistance bears to the driving moment caused by the action of the running water on the screw blades is extremely small, and consequently the variable resistance of this pivot will not be sensible in practice; thus the friction of the working parts is for all practical purposes a constant quantity. The bearings upon which the cylinder rotates are the only bearings exposed to water. They are made of steel, nickel-plated, and are lubricated by the water in which the instrument works.

The rate of the instrument was obtained by drawing it several times through still water, for a known distance, at different velocities, for which purpose it was attached to, and underneath, a float about 6 feet in length. By comparing a number of results obtained in this way the following formula was arrived at, viz.:—

$$V = 1 \cdot 2\, R + Q,$$

where V is the velocity of the instrument through the water, in feet per minute, or, which is the same thing, the velocity of the water with respect to the instrument; R the number of revolutions of the

cylinder per minute, and Q a quantity which vanishes when R is equal to or greater than 60, and increases, as R diminishes, in the ratio of 1 to 5, the general value of Q being $\frac{60 - R}{5}$,

$$\therefore V = 1{\cdot}2\,R + \frac{60 - R}{5} = 1{\cdot}2\,R + 12 - {\cdot}2\,R = R + 12,$$

for values of R less than 60, and

$$V = 1{\cdot}2\,R$$

for values of R greater than 60.

From this it follows that when the velocity of the stream is 12 feet per minute, the rotating cylinder is bordering upon motion, its moment of inertia being just balanced by the moment of the force due to the action of the running water on the screw blades.

The instrument will not measure a smaller velocity than 12 feet per minute when it is suspended from a boat at anchor, or from a fixed platform; but smaller velocities may be measured by it if drawn, with a known velocity, against the current. Thus if the instrument be drawn with a velocity of 20 feet per minute against a stream whose velocity is V, and the number of revolutions be 14,

$$20 + V = 14 + 12 = 26, \text{ and } \therefore V = 6.$$

In this way very small velocities may be measured.

The current meter when in use is always drawn back by the stream through a small distance, from the vertical line passing through the point of suspension, the amount increasing with the velocity of the stream and the depth to which the instrument is immersed. This distance is greatest when the rotating cylinder is at rest, because the screw blades, being then fixed, offer greater resistance to the water. When the cylinder is set free, by raising the spring, the resistance is diminished, and the instrument advances through a small distance to meet the stream. This advance will tend to increase the number of revolutions of the cylinder in a given time, but, on the other hand, it is equivalent to a momentary quickening of the stream, which helps to overcome the inertia of the cylinder and to set it in full rotation rather more quickly than would otherwise be the case. But the greatest error which could arise from this advance of the instrument is extremely small, compared with the whole number of revolutions made in a given time; by allowing the instrument to remain some minutes under water this small error is distributed over the whole number of turns, and becomes practically inappreciable. The

vertical depth of the instrument below the surface is also affected by the distance through which it is drawn back by the stream, but this error in the depth would be only a small fraction of the horizontal distance, and consequently it would not be necessary, even if it were possible, to take it into account.

To use the instrument, put back the stirrup upon the frame and raise the frame to the level of the eyes, holding the tail with the right hand and the pointed head with the left. The dials will then be seen through the glass, and their reading must be taken down. The instrument is next to be lowered into the water, started and stopped at known instants by the spring, then drawn up out of the water, and the reading again taken. The difference between this and the former reading will give the number of revolutions in the time observed. In Plate 8, Fig. 7, the frame which contains the mechanism is shown detached from the cylinder, the reading of the dials being 32,705.

The dials will record 100,000 revolutions of the cylinder, after which the same reading will recur. This number of revolutions is equivalent to 120,000 feet, or more than 22 miles. Thus the instrument might be left under water for eleven hours, in a stream running 2 miles an hour, before the dials would go through a complete period; and, even if the period were overrun, a comparison of the readings, with an approximate estimate of the velocity of the stream, would immediately reveal the fact.

The glass cylinders are constructed to bear a greater pressure of water than is to be found in any river, or other fresh water. They have been tested under a head of about 300 feet without injury, or leakage at the joints.

For deep-sea work the water is allowed to enter the cylinder, but it is intended to construct the instrument in a somewhat different manner, which will be described under the head of "Ship's Logs." It has been found by experiment with a cylinder filled with gun oil, that 400 revolutions per minute can be made by the cylinder without the resistance of the oil causing the suspended frame of wheels to turn over. This corresponds to a velocity of about 5½ miles an hour, which is probably much greater than that of any deep-sea current.

An important characteristic of this current meter is the rapidity with which it can be used. A velocity at any depth down to 20 feet can be taken with ease in five minutes, allowing the instrument a run of four minutes under water; in other words, only 20 per cent. of the whole time is required for observing and recording the instrumental readings. By using two instruments together

the time can be still further economised, and each instrument will remain a longer time under water.

FORM of FIELD BOOK for CURRENT METER.

$$\text{Rate of instrument, } 1\cdot 2 = \frac{\text{velocity in feet per minute}}{\text{number of revolutions per minute}}.$$

No. of Observation.	Times of Starting and Stopping.	Interval (min.)	Instrument Readings.	Differences.	Revolutions per minute.	Velocity. Feet per minute.	Mean adopted Velocity.	Remarks.
	H. M. S.							
1	3 2 15		23,714					
	3 5 15	3	23,927	213	71	85·2		
2	3 6 10		23,927					
	3 9 10	3	24,141	214	71·33	85·596	85·40	Station A.
3	3 11 20		24,141					
	3 15 20	4	24,513	372	93	111·6		
4	3 16 10		24,513					
	3 19 10	3	24,794	281	93·66	112·39	112	Station B.

To illustrate one of the uses of the current meter, the river Thames was gauged on the 1st of January, 1876; a section of the river was taken about ¼ mile below the railway bridge at Staines, and about fifty velocities in all were measured. The whole work was done between 9.30 A.M. and 2.30 P.M. During the first half of the time a strong breeze was blowing across the river, and during the latter heavy rain fell, both of which considerably impeded the work. Figs. 8 to 15, Plate 8, represent the plan of the site, a transverse section of the river, and six parallel sections of the mass water which passed through the transverse section in twelve seconds, the planes of these sections being perpendicular to that of the transverse section, and parallel to the direction of the stream. From the dimensions of the transverse section and the measured velocities, the quantity passing through this section was estimated to be 156,799 cubic feet per minute. The calculations by which this result was obtained are given in Appendix I.

On the plan are shown three irregular curved lines stretching across the river from end to end of the transverse section. These lines are the curves of flow, or velocity curves, at the surface, the mean depth, and the bottom, respectively, in twelve seconds from the section line. The ends of these curves are drawn with a free hand from experience in similar cases; they can, of course, be laid down with greater precision by taking more velocities at stations closer together, but the quantity which passes through the end portions of the section is very small compared with the whole flow, and it is therefore not of so much importance to

measure the velocities near shore with great accuracy. Moreover, the gauging in question is given rather as an illustration of the use of the current meter than as an exact determination of the flow of the river at a particular time; indeed, the unfavourable weather probably affected the results, and it is not unlikely that the curves of flow would have been more regular had the measurement been taken in calm weather.

Ship's Log and Deep-sea Current Meter.

This instrument is constructed on the same principle as the Current Meter, but with a different arrangement of the parts. Plate 9, Fig. 1, shows a vertical longitudinal section of the log, and the glass cylinder and mechanism are seen detached in Figs. 2 and 3. The light frame and tail being dispensed with, the rotating cylinder is furnished with large screw blades, and contains within it a glass tube and mechanism similar to that of the current meter. The cylinder is attached to a strong spindle which rotates in bearings contained within another tube of the same diameter, terminating in a solid ogival head. This log is not attached in the usual way to the log-line by a ring at its extremity, but the line is connected with the tube near to, and a little in front of, the centre of gravity of the whole instrument. By this means the log travels below the surface of the water, even when drawn up near the ship. The usual method of attaching the log-line to a ring at the front of the log causes a couple to come into action, which elevates the point of the log, giving it an upward direction, which quickly brings it to the surface. This couple disappears altogether when the log-line is attached at the centre of gravity.

A log so constructed will not only travel steadily below the surface of the water, but may be run alongside of the ship if drawn from the end of a spar projecting a few feet from the side. A log running constantly below the surface, is not so liable to foul weed or other floating matter, and when such fouling does happen, the point of the log dips and throws off the floating substance, and the log rights itself again.

The recording mechanism is not exposed to the action of the sea-water: it works smoothly inside the water-tight glass tube, which can be detached from the log. The reading of the dials is to be entered in the log-book, and the dial pointers are not set to zero each time the log is put overboard. This prevents errors arising, either from omission to set the pointers, or from their working loose from too frequent handling.

The reading of the pointers in Fig. 2 is 137·540. Suppose the log to be put overboard, and that, after one hour, the reading is found to be 149·790; the difference, 12·25 miles, is the run through the water in that time.

Another and more delicate form of log, intended to be used also as a deep-sea current meter, is shown in Plate 9, Figs. 4, 5, and 6. This instrument has an outer cylinder surrounding the screw blades, and the rotating cylinder turns upon two end pivots as in the current meter. The water which acts on the blades passes through this outer cylinder, and a protecting conical grating of copper throws off any floating substance which might impinge upon the log, while it allows sufficient water to pass to drive the blades. This instrument is much more sensitive to running water than the log previously described, and is intended chiefly as a deep-sea current meter. When used for this purpose water is allowed to enter the cylinder containing the mechanism, to protect it from being crushed by the pressure of the water at great depths.

As it would be impracticable to start and stop the rotation of this cylinder at great depths by a spring, as in the current meter, a self-acting starting and stopping gear is provided, as shown in Plate 9, Fig. 6. This consists of a small disc, cut away on one side, and terminating in a heavy sphere on the other, which swings freely on a pivot attached to the frame containing the wheel-work. On the spindle which supports this frame a pinion of four teeth is fixed, in such a position as to allow the teeth to pass freely through the opening on the disc, when the axis of the whole instrument is horizontal, or nearly so. But when the axis is much inclined from the horizontal, the disc passes between two consecutive teeth of the pinion and is caught by it, and the suspended frame then revolves with its supporting spindle, and consequently the wheel-work does not register the rotations.

This is the case when the instrument is descending in water, and also when it is being drawn up. Thus the rotations of the cylinder are registered only while the instrument is suspended at the depth at which it is desired to measure the velocity.

Deep-sea Current Indicator.

The object of this instrument is the determination of the direction of submarine currents by referring them to the magnetic meridian of the place. The instrument consists of a strong, heavy spherical shell of gun-metal, formed of two parts, which can be screwed together so as to form a water-tight case, terminating in

one direction in a solid cone, or cone-like protuberance, and in the opposite direction in a long cross tail or rudder, the axis of the cone passing through the centre of the spherical shell, and coinciding with the intersection of the blades of the cross tail. This axis may be conveniently called the principal axis of the instrument.

The shell is suspended from a strong stirrup, which strides across it, by two pivots whose axis is a diameter of the shell, and is perpendicular to the principal axis, and the whole instrument is balanced, or nearly so, upon its pivots when suspended by the stirrup. The stirrup is provided with a swivel at the top, to which a line is attached for the purpose of lowering the instrument into deep water. Accordingly, when the instrument is lowered into running water from a stationary platform, the water, acting on the rudder-like tail, causes the instrument to take up a position with its principal axis in the direction of the stream, and the point of the cone facing it. Inside the shell is a cylindrical box, suspended by gimbals upon two pivots fixed to the shell, with their geometrical axis coinciding with that of the two outer pivots, by which the whole instrument is suspended. This box contains a simple train of clockwork, and in its upper part a bar magnet, with a light graduated ring, balanced upon a fine pivot, the point of which coincides with the centre of the shell. The clockwork is so connected with the magnet that, at a given instant, it lifts it suddenly off the pivot and fixes it firmly against a glass plate immediately above. The clockwork can be set, by a time wheel, so as to fix the magnet after the lapse of any time up to one hour.

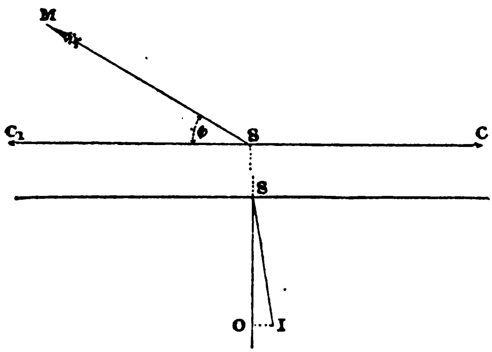
In Plate 9, Fig. 7 is a side elevation, and Figs. 8 and 9 are respectively vertical and horizontal longitudinal sections. Fig. 10 shows a general plan of the mechanism, and Fig. 11 a plan of the underside of the suspended box.

When the instrument is lowered into a current the principal axis of the instrument takes the direction of the current, while the magnet places itself in the magnetic meridian, and it is only necessary to secure the magnet in this position before drawing up the instrument. This is done by setting the clock to act upon the magnet at a known time, previous to lowering the instrument into the water, and it is sufficient to give the magnet four or five minutes to settle itself in the meridian before the lapse of this time. When the instrument is drawn up the magnet will be found fixed in position, showing at once the angle between the magnetic meridian and the direction of the current, or the magnetic

bearing of the current below. The direction of the compass is not affected by the rise and fall of the ship; this merely causes a small oscillation of the case in a vertical plane about the axis of its pivots, which axis is always horizontal, and this motion of the case does not affect the direction of the instrument. When the current indicator is lowered from a ship at anchor, or otherwise at rest, or from a ship moving with the same velocity as the surface current but in the opposite direction, so that it remains vertically above the same point of the earth's surface, the reading obtained from the magnet shows, directly, the magnetic bearing of the submarine current. Under the same circumstances the deep-sea current meter will determine the velocity of the same current. When, however, the ship is in motion with the surface current, or in any other direction, the indications both of the current meter and current indicator are affected by this motion; but when these instruments are used in combination they still suffice to determine the velocity and direction of the submarine current, provided the course of the ship and its speed are known.

It should be remarked that in no case will the instrument be in the vertical line through the point of support except the ship be at rest in motionless water. The horizontal motion of the ship will, however, be impressed upon the instrument suspended from it. Consider first the case of a ship at rest upon the surface of the water; let S, Fig. 1, be the position of the ship, S M the

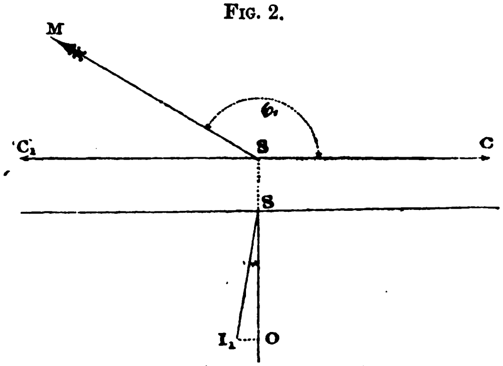
FIG. 1.



magnetic meridian, and S C the direction of the submarine current; then the instrument will point in the opposite direction S C_1, and the angle shown by it will be the angle M S C_1, marked ϕ in the

diagram. If the current is in the opposite direction S C_1, Fig. 2, the instrument will point in the direction S C, and will register the angle M S C, marked ϕ_1. Figs. 1 and 2 also show vertical ideal

FIG. 2.

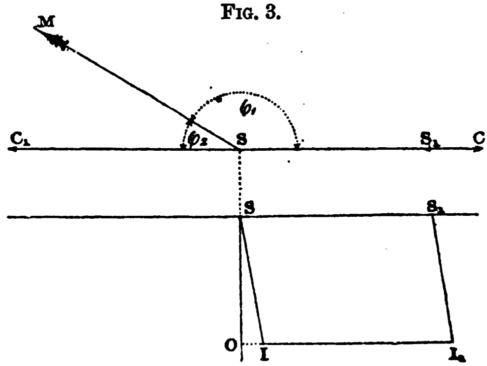


sections along the line C C_1, S O being a vertical from the ship S, and I the position of the current indicator, when the current runs in the direction S C, Fig. 1, and I_1, its position when the current runs in the opposite direction S C_1, Fig. 2.

The current meter will, under the same circumstances, measure the velocity of the current in whichever direction it may run, and in the case of a ship being stationary no calculations are required.

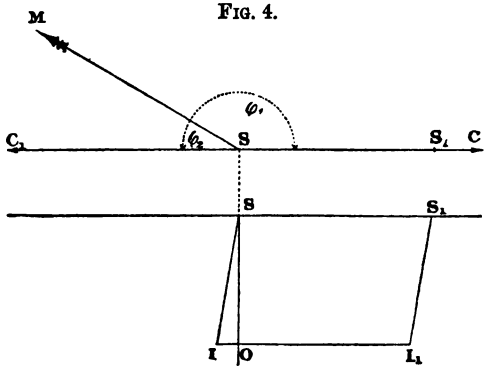
When the ship is in motion the problem is more complicated. Before considering the general case it will be well to examine the simplest case, viz., that in which the motion of the ship is in the same direction as the submarine current, or in the opposite direction. Fig. 3 represents the case in which the ship and current

FIG. 3.



move in the same direction, the speed of the current being greater than that of the ship; and Fig. 4 that in which the speed of the current is less than that of the ship. Fig. 4 also represents the case

FIG. 4.



in which the ship and current move in opposite directions. In each figure S M represents the magnetic meridian, and S S_1 the motion of the ship in a given time.

The suspended instrument will travel through the same distance S S_1 in the same time, and it will point in the direction S C, if the velocity of the submarine current is less than that of the ship, and in the opposite direction S C_1 when the velocity of the submarine current is the greater. In the former case it will indicate the angle ϕ_1, and in the latter the angle ϕ_2, so that the current indicator alone will not determine in which of these two directions the current flows, unless it is known whether the speed of the ship is greater or less than that of the current.

But the current meter will supply this information directly; for, when the ship is moving in the same direction as the submarine current, the current meter registers the difference of their velocities, and when the ship and submarine current are moving in opposite directions the current meter registers the sum of their velocities. Thus all ambiguity will be removed by using the two instruments in combination; for, let V be the velocity of the ship and S that of the current, and conceive the whole mass of water to have a motion impressed upon it equal and opposite to that of the ship. The ship will then be at rest, and the instrument will be acted on by a current having a velocity S − V when the ship and current move in the same direction, and a velocity S + V when they move in opposite directions.

If then p be the reading of the current meter,

$$p = \mathrm{S} - \mathrm{V} \text{ in the former case,}$$

and
$$p = \mathrm{S} + \mathrm{V} \text{ in the latter.}$$

When S is greater than V, the angle shown by the current indicator will be the angle ϕ_2, and when S is less than V the instrument will give the angle ϕ_1, and thus the velocity and direction are completely determined, and

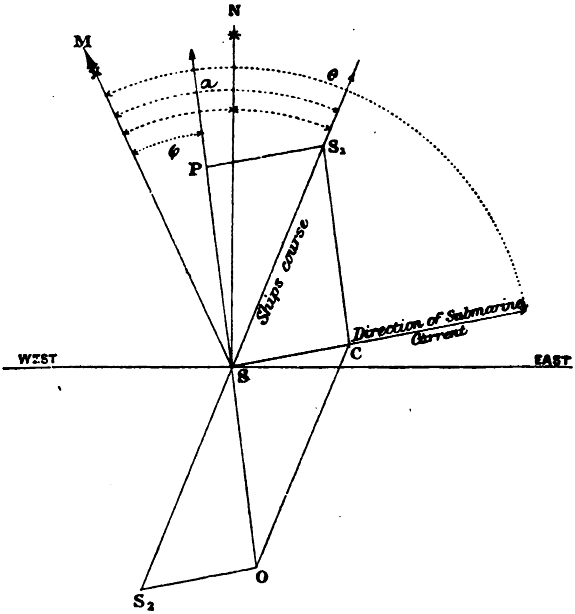
$$\mathrm{S} = p \pm \mathrm{V},$$

$+$ or $-$, according as the ship and current move in the same or in opposite directions.

Consider lastly the general case:—

Let SM (Fig. 5) represent, as before, the magnetic meridian,

Fig. 5.



SS_1 the motion of the ship in a known time T, with a velocity of v miles per hour, in a direction making an angle a with the magnetic meridian.

Let SC represent the direction of the submarine current making an angle θ with this meridian, and suppose s the velocity of this

current in miles per hour, and S C the run of the current in the time T. As before, the ship and instrument may be supposed at rest, if the velocity v be impressed upon both in the direction $S_1 S$, or it be conceived that this velocity is applied to the whole mass of water in the same direction. Join $C S_1$ and draw S P parallel to it: then S P is the direction in which the current indicator will point while the ship moves from S to S_1. For, the ship being reduced to rest, the instrument is subject to the action of the current which moves parallel to S C, through the distance S C in the time T, while the whole mass of water moves in the direction $S_1 S$ through the distance $S S_2$ (equal to $S_1 S$) in the same time T, consequently S O, the diagonal of the parallelogram constructed on the lines S C and $S S_2$, is the effective direction of the moving water with respect to the instrument, and as this diagonal is in the line S P, the instrument will turn in that direction.

The same reasoning applies to the current meter, and therefore this instrument will measure the distance $C S_1$, or S P, while the ship moves from S to S_1.

The calculations for determining the direction and velocity of the current present no difficulty. Let p represent the distance S P, and ϕ the angle M S P.

Then
$$\frac{S C}{S S_1} = \frac{\sin S S_1 C}{\sin S C S_1},$$

and
$$\frac{C S_1}{S S_1} = \frac{\sin C S S_1}{\sin S C S_1},$$

that is
$$\frac{s}{v} = \frac{\sin(\alpha - \phi)}{\sin(\theta - \phi)} \quad . \quad . \quad . \quad . \quad (1)$$

and
$$\frac{p}{v} = \frac{\sin(\theta - \alpha)}{\sin(\theta - \phi)} \quad . \quad . \quad . \quad . \quad (2)$$

From (2)
$$\frac{\sin\theta \,.\, \cos\alpha - \cos\theta \,.\, \sin\alpha}{\sin\theta \,.\, \cos\phi - \cos\theta \,.\, \sin\phi} = \frac{p}{v},$$

$$\therefore \frac{\tan\theta \,.\, \cos\alpha - \sin\alpha}{\tan\theta \,.\, \cos\phi - \sin\phi} = \frac{p}{v},$$

$$\therefore \tan\theta = \frac{v\sin\alpha - p\sin\phi}{v\cos\alpha - p\cos\phi} \quad . \quad . \quad (3)$$

This last equation will determine θ when v, p, α and ϕ are known, and then s can be found from equation (1).

As an example, suppose a ship to sail due N.N.E. for 3 miles in

a known time, at a part of the earth's surface where the magnetic variation is 25° west, and that the current meter registers $2\frac{1}{2}$ miles in the same time, and the current indicator bears 18° to the east of the magnetic meridian.

Then $\qquad a = 25^\circ + 22^\circ\ 30' = 47^\circ\ 30'; \ \phi = 18;$

$\qquad\qquad v = 3, \text{ and } p = 2 \cdot 5.$

$$\text{Therefore } \tan\theta^\circ = \frac{3 \sin 47^\circ\ 30' - 2\cdot 5 \sin 18^\circ}{3 \cos 47^\circ\ 30' - 2\cdot 5 \cos 18^\circ}$$

$$= \frac{12 \times \cdot 7372773 - 10 \times \cdot 3090170}{12 \times \cdot 6755902 - 10 \times \cdot 9510565}$$

$$= \frac{8\cdot 8473276 - 3\cdot 0901700}{8\cdot 1070824 - 9\cdot 5105650}$$

$$= -\frac{5\cdot 7571576}{1\cdot 4034826}$$

$$\therefore \tan(180^\circ - \theta^\circ) = -\tan\theta^\circ = \frac{5\cdot 7571576}{1\cdot 4034826}$$

$$\therefore \log\tan(180^\circ - \theta^\circ) = 10 + \log 5\cdot 7571576 - \log 1\cdot 4034826$$

$$10 + \log 5\cdot 7571576 = 10\cdot 7602083$$

$$\log 1\cdot 4034826 = 0\cdot 1472056$$

$$\therefore \log\tan(180^\circ - \theta^\circ) = 10\cdot 6130027$$

$$\text{but } \log\tan 76^\circ\ 18' = 10\cdot 6130131$$

$$\therefore 180^\circ - \theta^\circ = 76^\circ\ 18' \text{ omitting seconds,}$$

$$\therefore \theta^\circ = 103^\circ\ 42'.$$

To find the velocity of the current,

$$s = v\frac{\sin(a - \phi)}{\sin(\theta - \phi)}$$

$$\therefore \log s = \log v + \log\sin(a - \phi) - \log\sin(\theta - \phi)$$

$$v = 3,\ a - \phi = 47^\circ\ 30' - 18^\circ = 29^\circ\ 30'$$

$$\theta - \phi = 103^\circ\ 42' - 18^\circ = 85^\circ\ 42'$$

$$\log v = \log 3 = 0\cdot 4771213$$

$$\log\sin(a - \phi) = \log\sin 29^\circ\ 30' = 9\cdot 6923388$$

$$10\cdot 1694601$$

$$\log\sin(\theta - \phi) = \log\sin 85^\circ\ 42' = 9\cdot 9987758$$

$$\therefore \log s = 0\cdot 1706843$$

$$\text{but } \log 1\cdot 4814 = 0\cdot 1706723$$

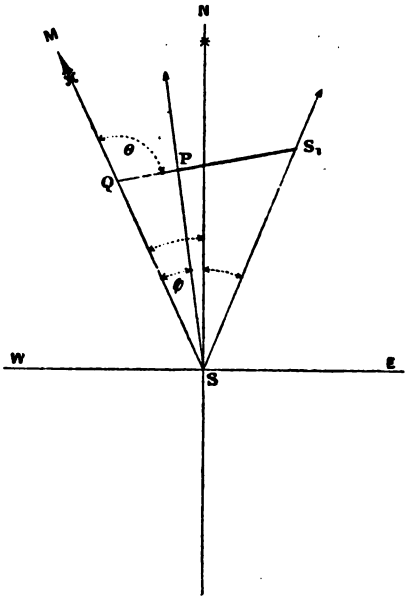
$$\therefore s = 1\cdot 4814.$$

Thus the current runs with a velocity of 1·4814 mile per hour, and its bearing is 103° 42′ from the magnetic meridian, or 78° 42′ east of north.

The velocity and direction of the current may also be found by a simple geometrical construction as follows, giving the same results as the preceding calculation:—

In Fig. 6 lay down the meridian S N, the magnetic meridian

Fig. 6.



S M, and the ship's course $S S_1$, and draw S P in the direction pointed out by the current indicator; mark off S P for the distance measured by the current meter on the same scale on which $S S_1$ represents the run of the ship, and join $P S_1$. This line will represent the submarine current in magnitude and direction. Producing $S_1 P$ to meet S M in Q, the angle P Q M shows the bearing of the current from the magnetic meridian.

The Paper is illustrated by drawings, from which Plates 8 and 9 and the woodcuts have been compiled.

[Appendices.

APPENDICES.

1. Flow of the River Thames, Jan. 1, 1876.

The flow of the river Thames on the 1st of January, 1876, estimated from measurements taken below the railway bridge at Staines, was as follows:—

The tranverse section of the river was taken at right angles to the main direction of the stream, and measurements were made of the velocity of the water, at the surface, bottom, and mean depth, at a number of equidistant stations in this transverse section. From these velocities and the corresponding depths, the areas of a series of parallel sections of the volume of water passing through the transverse section in a given time were obtained, and from these areas and the known dimensions of the tranverse section the volume of water was computed. The parallel sections alluded to are parabolic in form, each being approximately a portion of a parabola, the axis of which is horizontal, near to and below the surface. The areas of these sections may therefore be readily calculated from the formula,

$$\text{Area} = \frac{d}{6}\left\{v_s + v_b + 4\,v_m\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(A)}$$

in which d is the depth of the water,

v_s the velocity at the surface,

v_b „ „ bottom,

and v_m „ „ mean depth.

When these areas have been computed, the volume of the mass of water passing through the transverse section, between the two most distant velocity-stations, can be found from the prismoidal formula,

$$\text{Volume} = \frac{h}{3}\left\{\Sigma\,\text{A (extreme)} + 2\,\Sigma\,\text{A (odd)} + 4\,\Sigma\,\text{A (even)}\right\}. \text{(B)}$$

in which h is the distance between any two consecutive stations,

Σ A (extreme) the sum of the areas of the extreme parallel sections,

Σ A (odd) the sum of the areas of the parallel sections which are of an odd order, omitting the extremes, and

Σ A (even) the sum of the areas of the parallel sections which are of an even order.

To the quantity so obtained must be added the small quantities of water passing between each of the two most distant velocity-stations and the nearer bank.

From the formula (A) the following table of areas has been calculated:—

Velocity Station.	Area in Square Feet in Twelve Seconds.
No. 1.	114·48
A	267·36
No. 2.	288·40
B	264·90
No. 3.	244·42
C	225·03
No. 4.	200·42
D	169·03
No. 5.	166·44
E	159·50
No. 6.	150·36
F	136·60
No. 7.	120·92
No. 8.	106·50

The volume of the water passing between the stations No. 1 and No. 7 may now be found by the formula (B):—

For Σ A (extreme) $=$ sum of areas at stations Nos. 1 and 7:

$$= 114 \cdot 48 + 120 \cdot 92$$
$$= 235 \cdot 40.$$

Σ A (odd) $=$ sum of areas at stations Nos. 2, 3, 4, 5, and 6:

$$= 288 \cdot 40 + 244 \cdot 42 + 200 \cdot 42 + 166 \cdot 44 + 150 \cdot 36$$
$$= 1{,}050 \cdot 04.$$

Σ A (even) $=$ sum of areas at stations A, B, C, D, E, and F:

$$= 267 \cdot 36 + 264 \cdot 90 + 225 \cdot 03 + 169 \cdot 03 + 159 \cdot 50 + 136 \cdot 60$$
$$= 1{,}222 \cdot 42$$

and $h = 12 \cdot 5$ feet

$$\therefore \ V = \frac{12 \cdot 5}{3}\left\{235 \cdot 40 + 2 \times 1{,}050 \cdot 04 + 4 \times 1{,}222 \cdot 42\right\}$$
$$= 30{,}104 \cdot 75 \text{ cubic feet in twelve seconds.}$$

Therefore the volume per minute is 150,524 cubic feet.

The mass of water between station No. 1 and the bank is approximately pyramidal in form, and its volume is $114 \cdot 48 \times \frac{7 \cdot 5}{3} = 286$ cubic feet.

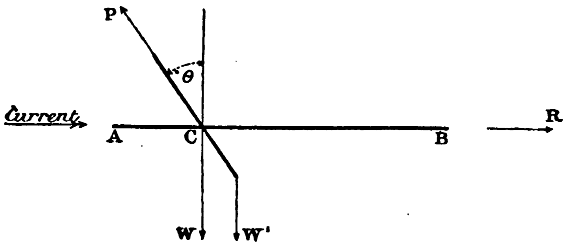
The volume of the water between the stations No. 7 and No. 8 is $\frac{121 + 106}{2} \times 5 = 567$ cubic feet; and the volume of the end portion, between the station No. 8 and the bank, is approximately equal to the parabolic area inclosed by the velocity-curve at the mean depth multiplied by the depth, *i.e.* it is equal to $\frac{2}{3} \times 5 \cdot 5 \times 18 \cdot 3 \times 6 = 402$ cubic feet. Therefore the total quantity outside the stations Nos. 1 and 7 is $286 + 567 + 402 = 1{,}255$ cubic feet in twelve seconds, and, therefore, the quantity per minute is 6,275 cubic feet. Adding this quantity to the main volume already obtained, the total flow is 156,799 cubic feet per minute.

Cor.—The mean velocity of the water for the whole section may be found by dividing the total flow by the area of the transverse section.

This gives a mean velocity of 127·12 feet per minute.

2. Mechanical Principles on which the Current Meter is constructed.

Fig. 1.



A B represents the axis of the instrument, A being the point of the ogival head, and B the extremity of the tail, and C its centre of gravity. B C is about three times the length of A C.

The forces which act upon the instrument are: W, its weight in water; R, the resistance which it offers to the stream; and P, the pull upon the stirrup, which inclines forward through some angle θ from the vertical.

These three forces, P, W, and R, are in equilibrium at the point C.

$$\therefore\ P \cos\theta = W, \text{ and } P \sin\theta = R.$$

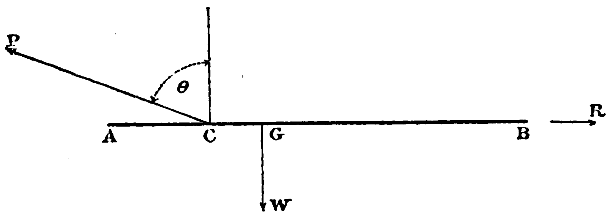
The position of the axis A B is manifestly one of stable equilibrium when in the direction of the current; for if it be displaced about the point C, the action of the current will restore the axis to its former position. An increased velocity in the current increases R, and therefore both P and θ. This increase of θ can be prevented, when desired, by suspending a weight from the two ends of the stirrup.

Let W′ be the effect of this weight in the vertical direction, then the former of the above equations becomes $W + W' = P\cos\theta$.

Thus θ may be made as small as desired by sufficiently increasing W′.

The Ship's Log is constructed on the same principles as the current meter.

Fig. 2.



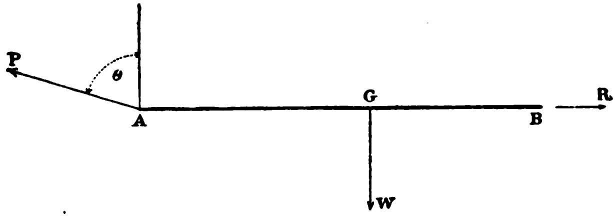
Let A B represent its axis, G the centre of gravity, C P the direction of the pull of the log-line at C, W the weight of the log in water, and R the resistance of the water. Then $P\cos\theta - W$ is the lifting force upon the log, which will consequently rise through the water until this force vanishes, *i.e.* until $\theta = \cos^{-1}\frac{W}{P}$.

θ can never be so great as a right angle, and therefore this log can never rise to the surface in smooth water, and its tendency to rise in rough water is

reduced to a minimum. Again, P sin θ − R is the effective tractive force in a horizontal direction, and W × C G is the moment tending to raise the point A and to give the axis of the log an inclination upwards. This moment can be made as small as desired by diminishing the distance C G, and therefore this log may be made to travel with its axis horizontal, and below the surface of the water.

Let A B represent the axis of a log constructed in the usual manner, with the log-line attached to its front A by a ring.

FIG. 3.



Let G be its centre of gravity, W its weight in water, and P the pull on the log-line, the direction of which at A makes an angle θ with the vertical.

In this case the moment W × A G, tending to raise the point A, and give the log an inclination upwards, can never be made small; and a log so constructed can never travel with its axis horizontal. Its inclination upwards causes the water to strike against the under side of the log, which speedily brings it to the surface.

MEMOIRS OF DECEASED MEMBERS.

Mr. CRAWFORD JAMES CAMPBELL was born at Edge Hill on the 18th of October, 1832, and was educated first by a private tutor, afterwards at a school near Falkirk. Although offered an appointment in the Royal Engineers, he preferred to become a Civil Engineer, and in 1847 he was articled for five years to Mr. Sturges Meek, then Resident Engineer of the East Lancashire railway, when the line from Liverpool, through Ormskirk, to Preston was under construction; and after the expiry of his indentures he remained for a year and a half as an assistant. On the 4th of December, 1853, he sailed for India, as an Assistant Engineer, in the service of the East Indian Railway Company, and was, soon after his arrival, engaged on preliminary surveys in the North-West Provinces, between Allahabad and Futtehpore, and subsequently, from the latter end of 1854, on the upper end of the Mirzapore and Allahabad contract, being promoted to the grade of Resident Engineer in April 1856, when he received charge of the construction of 30 miles of the line in the Allahabad district, under the late Mr. R. M. Mantell. In common with the other members of the staff stationed in that neighbourhood, on the outbreak of the Mutiny in 1857, he was ordered to the Allahabad Fort, was enrolled as a volunteer, and helped to defend the walls. When quiet was restored, he returned to his residence on the river Tonse, and commenced the foundations for the large girder bridge across that river.

He resigned the company's service in July 1859 to join the Public Works Department of the Government of India as an Executive Engineer, 3rd grade, and was posted to the Punjâb, where he rendered good service in charge of the Delhi Division. He was intrusted with the construction of all the military buildings, amongst them the three-storied barracks rendered necessary by the permanent location of an European force, for the first time, at Delhi. In November of the following year he was promoted to Executive Engineer, 2nd grade. In May 1864 he obtained another step of promotion, and continued to serve at Delhi till

September 1867, when he was transferred to the Central Provinces as Officiating Superintending Engineer. In December of the same year he was appointed to officiate for a short time as Assistant Secretary in the Public Works Department. His services were then made over to the Government of Bengal for employment as Consulting Architect. In May following he applied for and was transferred to the Punjâb as Officiating Superintending Engineer of the Lahore Circle; and in November was retransferred to the Central Provinces in the same position. In August 1869 he attained the permanent rank of Superintending Engineer, 3rd grade, and in 1870 was commended by the Central Provinces Administration for having discharged his duties while in the Jubbulpore Circle with much credit and energy. He was, however, held by the Government of India to have been to blame for imperfect supervision of the Saugor Barracks, which were afterwards condemned as unsafe. Notwithstanding his chagrin at what he knew and felt to be an unfair and a wrong decision, he continued to give his best services to the Government. In April 1870 he was transferred to the State Railway branch, and was appointed to take charge of the Indore (now Holkar) Railway Survey, and in November 1871 received the thanks of the Government of India for the successful manner in which the surveys between Khundwa and Indore were carried out. His tact and ability carried his staff with him as one man, and an *esprit de corps* was formed, which is so difficult to create in a section of a heterogeneous body like the Indian Public Works Department. The construction of this line being relegated to contractors, he was transferred to the more important charge of the Indus Valley State railway, as Engineer-in-Chief, with the pay and rank of a Superintending Engineer, 1st grade, which appointment he held till March 1873, when he went on furlough for twelve months. On his return, in March 1874, he was posted to the charge of the Tirhoot State railway, which he continued to hold till February 1876, when severe illness compelled him to go on sick certificate without loss of time; but his health was so injured by hard work and exposure that he had not strength to battle with disease, and died at Naples on the 10th of April, 1876.

Mr. Campbell had been elected a Member on the 6th of December, 1870.

MR. ARTHUR JOHN DODSON, son of Mr. John Dodson, of H.M. Customs, and of Clara, his wife, a sister of the authors, James and Horace Smith, was born at Clapham, Surrey, on the 1st of August, 1818. He was educated at two private schools in the neighbourhood, but the greater part of his acquirements were due to diligent reading and patient study at home. From boyhood he was always fond of scientific pursuits, and attained, when quite young, a considerable knowledge of geology, chemistry, and mechanics. In 1836 he was articled to the late Mr. I. K. Brunel, V.P. Inst. C.E., soon became a good draughtsman, and was employed, both before and after the expiration of his articles, in assisting to prepare the designs for various sets of machinery on the Great Western railway. He was elected an Associate of the Institution on the 13th of June, 1841, and about this time presented a "Description of the Hydraulic Traversing Frame at the Bristol Terminus of the Great Western Railway,"[1] for which he was awarded a Walker premium. From 1844 to 1849 he was employed on the Great Western railway as an Assistant Engineer; at first in the construction of the branch line from Didcot to Oxford, under Mr. R. J. Ward, M. Inst. C.E.; then on parliamentary works in connexion with the Berks and Hants and the Berks and Hants Extension railways, and the proposed construction of the direct line to Exeter; and subsequently in the construction of a district, from Reading to Woolhampton, of the Berks and Hants railway, under Mr. T. H. Bertram. From 1849 to 1856 he was engaged at Bangor, in North Wales, as the Engineer of slate quarries, on his own account, the whole of the machinery and works being erected and carried out from his designs. He next joined Mr. E. I. J. Dixon, the patentee of machinery for the manufacture of slate ridge-rolls, to supersede the use of lead on the roofs of houses. The firm took premises at Bangor, and erected steam-power to carry out the invention; and there they also designed, and jointly patented and erected, further improved machinery, for converting slate into various useful purposes. This partnership was determined by mutual consent in 1861, and in the following year Mr. Dodson entered the service of the Madras Irrigation and Canal Company, and as a District Engineer had charge of the execution of important works in the Hindus and Bowanassey Divisions, which were completed under his superintendence. He became a Member of the Institution by transfer on the 5th of April, 1870; returned to England during a temporary suspension of the works in 1871,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 127.

went back to India as one of the Company's Conservancy Engineers in 1873, which position he held until the Chief Engineer, Mr. J. Herbert Latham, M. Inst. C.E., left on sick leave in 1875, when Mr. Dodson was appointed acting Chief Engineer. He died very suddenly from cholera, after a few hours' illness, on the 27th of January, 1876, while visiting a friend at Yercand, on the Shevaroy Hills.

Mr. Dodson was careful, painstaking, and exact in all that he undertook; quiet, gentlemanly, and well educated, with a taste for literary pursuits. A sincere and consistent Christian, a loving son and brother, a warm and true-hearted friend, he was regarded by those who knew him with the utmost affection and esteem.

MR. JAMES MAY, fourth son of Mr. Andrew May, of the Caledonian Canal, and brother of Mr. George May, M. Inst. C.E., for many years Engineer and superintendent of the same work,[1] was born at Inverness, on the 1st of November, 1818. He was educated at the Inverness academy until the age of thirteen, when he went to Glasgow College, and studied there during four sessions. He was then for a short time in his brother's office, but subsequently served a pupilage under Mr. John Gibb, M. Inst. C.E., and was for several years engaged in the construction of the Aberdeen and the Edinburgh and Glasgow railways. Soon after the completion of these lines he was, in December 1849, appointed by Messrs. Walker and Burges assistant to the late Mr. Thomas Rhodes, M. Inst. C.E., then resident Engineer of the Harbour of Refuge works in Alderney. He continued in this capacity till 1859, when he succeeded Mr. Rhodes as Resident Engineer. He remained in charge of that undertaking—of which a detailed account was presented to the Institution by his successor (under Sir John Hawkshaw), Mr. Vernon Harcourt[2]—till 1870, when, on the recommendation of Mr. McClean, M.P., Past-President Inst. C.E., he was appointed to organise and superintend the extensive Harbour works at Alexandria, to be carried out by Messrs. Greenfield and Co., under contract with the Egyptian Government. The prin-

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 595.
[2] *Ibid.*, vol. xxxvii., p. 60.

cipal work is a breakwater, about 2 miles long, formed in a depth of 24 feet by a bank of concrete blocks, each about 20 tons weight, placed at random. This was virtually completed in the unprecedentedly short time of two years from the date of the deposit of the first block, and is a remarkable instance of what can be accomplished by the English capitalist and engineer when allowed full scope for their energies. Mr. May left Alexandria in 1873, having won the respect of the members of the firm he represented, and returned to reside in Alderney for a time. In the following year he was requested by Mr. William Parkes, M. Inst. C.E., to undertake the superintendence of the Madras Harbour works then in contemplation. It was not, however, till March 1875 that the final sanction of the Government was given to these works, and his appointment to the superintendence of them was confirmed. He arrived in Madras in June, and in the month of December 1875 the work was inaugurated by his Royal Highness the Prince of Wales setting a memorial stone, with an imposing ceremony, at which Mr. May assisted. But his labours were drawing to a close. Early in the following year he suffered from an affection of the throat, which proceeded to ulceration, and ultimately prevented his taking sufficient nourishment. He however persevered in attending to his duties till the beginning of April, when he was forced to give way. He lingered with increasing weakness, but still with a hope that he might be removed to a more invigorating climate, till the 4th of May, when he passed away, far from his family and old friends, but untiringly attended by those who had learned to love and value him after an acquaintance of only a few months. His remains were followed to the grave on the following day by the whole of his staff, and by many of the residents of Madras, official and mercantile.

Few engineers have the opportunity of spending twenty consecutive years in the execution of one work; but the result in Mr. May's case was a remarkable unanimity of testimony in his favour from all classes with whom he came in contact. On his departure for India this was volunteered from all quarters. High Government officials and rough working-men concurred with his equals and associates in their opinion of his character and qualifications for the new sphere on which he was about to enter. In professional matters he was modest and retiring almost to a fault, seldom volunteering an opinion even within the limits of his own large and special experience; but his accuracy, uprightness, and impartiality, with an even temper and love of conciliation, could not but be apparent to every one with whom he came in contact;

and it was these high qualities which gained for him such universal respect.

Mr. May was elected a Member on the 3rd of May, 1864.

MR. ROBERT NAPIER, Engineer and shipbuilder, of Glasgow, late President of the Institution of Mechanical Engineers, Member of the Institution of Civil Engineers, Chevalier of the Legion of Honour, and Commander of the Order of Danneborg (First Class), was born at Dumbarton on the 18th of June, 1791, his father being a blacksmith and a respected burgess of that town. In 1807 he was apprenticed to his father for five years; from 1812 to 1815 he wrought in Edinburgh and in Glasgow as a blacksmith and mechanic, working for a short time under Mr. Robert Stevenson, M. Inst. C.E., in the former city. In 1815 Mr. Napier received £50 from his father, with £45 of which he bought the tools and the good-will of a small blacksmith's shop in the Gallowgate, Glasgow, leaving £5 of working capital, with which sum he started in business, employing at first only two apprentices. In 1821, the business having increased, he engaged in iron-founding and engineering at Camlachie, at the east end of Glasgow, where, in 1823, he made his first marine engine for the "Leven" steamboat, built to ply between Dumbarton and Glasgow.[1] The success of this engine led so rapidly to other orders for marine engines that he found it necessary, in 1828, to remove to larger and more con-

---

[1] The following is a list of the vessels either engined or built, or both engined and built, by Mr. Napier. His usual practice was to contract both for hull and engines. When, in the earlier days of his career, the vessels were of wood, the hulls were built by sub-contract, generally by the late Mr. John Wood, of Port Glasgow, with whom he worked amicably for many years.

Name.	Year.	Name.	Year.	Name.	Year.
"Leven"	1823	"Glow-worm"	1830	"Shandon"	
"Ben Lomond"		"Queen Adelaide"		"Robert Napier"	
"New Dumbarton"		"Mona's Isle"	1831	"Vulcan"	
"Lady of the Lake"		"Windsor Castle"	1832	"Dundee"	1834
"Helensburgh"		"City of Glasgow"	,,	"Perth"	,,
"Aimwell"		"John Wood"	,,	"Albert"	,,
"St. Andrew"		"Mona"		"Duchess of Sutherland"	
"Ardincaple"		"Hero"			
"Clarence"		"Water Witch"		"Isabella Napier"	
"Stirling Castle"		"Castle Finn"		"Queen of the Isle"	
"Victoria"		"Tamar"		"St. Columb"	
"Tulliallan"		"Elbe"		Engine for South America	
"Sultan"		"Maid of Bute"			
"Greenock"		"Isle of Bute"		"Bernice"	1836
"Arran Castle"		"Nile"		"London"	,,
"Menai"	1830	"Superb"		"Zenobia"	1837

venient premises in Washington Street, adjoining the harbour of Glasgow, and in 1835 he added to these the engineering works at Lancefield, and, in 1841, the shipbuilding yard at Govan, about 1 mile from Glasgow. At this yard Mr. Napier (and subsequently the firm of Messrs. R. Napier and Sons) built many first-class steamers of all sizes for the mercantile marine and for war purposes, for various countries, employing at times upwards of three thousand workpeople.

Mr. Napier's early connection with steam navigation deserves to be specially noticed. In 1830 he was associated with the City of Glasgow Steam Packet Company, and engined most of their vessels running between Glasgow and Liverpool. The success of that line led to his being applied to, in March 1833, by a company in London (Mr. Patrick Wallace being his correspondent) for his opinion on the practicability of successfully navigating the Atlantic with steam-vessels between Liverpool and New York. His report was decidedly favourable, but the scheme was ultimately abandoned for want of funds. In 1834 the steam-ships "Dundee," "Perth," and "London," belonging to the Dundee and London Shipping Company, were contracted for and engined by him; the

---

Name.	Year.	Name.	Year.	Name.	Year.
"Commodore"	1837	India, No. 2	1841	"Prince of Wales"	1845
"Victoria"	,,	"Acbar"	,,	"Thetis"	,,
Engines for Turkish Government (3 pairs)	,,	"Palermo"	,,	"Fire Queen" No. 2	1846
"Sovereign"	,,	Sultan's Barge	,,	"Brian Boiroimhe"	,,
"Tartar"		"Fin McCoul"	1842	Engine for East India Co.	,,
"Rover"		"Precursor"	,,	Engines for Turkish Government (4 pairs)	,,
"Circassian"		"King Orry"	,,	"Copenhagen"	,,
"Duke of Richmond"		"Thunderbolt"	,,	"Tynwald"	,,
"Hobart Town"	1838	"Hibernia"	1843	"Viceroy"	,,
"Isle of Arran"		Engine for Rio de Janeiro	,,	"Duke of Sutherland"	,,
"New Sultan"		"Vanguard"	,,	"Earl of Aberdeen"	1847
"Eclipse"		"Dundalk"	,,	"Pride of Erin"	,,
"Foyle"		"Water Cure"	,,	"Lyra"	,,
"British Queen"	1839	"Fire Queen," No. 1	1844	"Satellite"	,,
"Fire King"		"City of London"	,,	"Leinster Lass"	1848
"Vesuvius"	1840	"Fame"	,,	"Thistle"	,,
"Stromboli"	,,	"Dolphin"	,,	"America"	,,
"Admiral"	,,	Engine for Rio de Janeiro	,,	"Niagara"	,,
"Britannia"	,,	"Blue Bell"	1845	"Dauntless"	,,
"Acadia"	,,	"Jackall"	,,	"Europa"	,,
"Caledonia"	,,	"Lizard"	,,	"Canada"	1848
"Columbia"	,,	"Bloodhound"	,,	"Simoom"	1849
"Londonderry"	1841	"Cambria"	,,	"Leviathan"	,,
Engines for Turkish Government	,,	"Rambler"	,,	"Emperor"	,,
India, No. 1	,,	"Queen of Beauty"	,,		
		"Ben-my-Chree"	,,		

hulls, by Mr. John Wood, of Port Glasgow, being long noted for their fine finish, for keeping their sheer so well when compared with other vessels, and for great regularity in sailing. In 1836 he supplied the Honourable East India Company with the "Bernice." In 1839 he provided the machinery for the steam-ship "British Queen," built to ply between this country and New York, which machinery was constructed to work either with the common jet-condenser, or with the late Mr. Samuel Hall's patent surface condenser. He also, about this time, built the steam paddle yacht "Fire King," for the late Mr. Thomas Assheton Smith, which vessel was the first of any size with fine hollow lines. She was built from Mr. Smith's own model, and on trial proved the fastest vessel then afloat. In this year also (1839) Mr. Napier, besides subscribing liberally towards the trial voyage of the "Sirius," from Great Britain to America, contracted with the Hon. Samuel Cunard for three steamers of 1,000 tons and 300 H.P. each, to ply between Great Britain and North America with the mails. Mr. Napier being, however, convinced that vessels of this size were too small for such a trade, induced Mr. Cunard, after a time, to adopt his views;

Name.	Year.	Name.	Year.	Name.	Year.
"Bolivia"	1849	"Arabia"	1852	"Garland"	1855
"Hamburgh"	"	"Malvina"	1853	"Twilight"	"
"Robert Napier"	1850	"Lady Eglinton"	"	"Aquilla Imperiale"	"
"City of Worcester"	"	"Duke of Wellington"	"		
				"Progresso"	1856
"Asia"	"	"Wibourg"	"	"Coromandel"	"
"Victoria" (1)	"	"Colombo"	"	"Fethia"	"
"Africa"	"	"Emeu"	"	"Packi Zafer"	"
"Rose"	"	"Messina"	1854	"Niger"	"
"Wizard"	"	"Black Swan"	"	"Napoleon III."	"
"Concordia"	"	"Malta" (1st)	"	"Queen Victoria"	"
"Grecian"	"	"London"	"	"Erebus"	"
"Wide Awake"	"	Dredger for Ayr	"	"Seine et Rhone"	"
"Arabian"	1851	"Vulcan"	"	"Terror"	"
"Santiago"	"	"Her Majesty"	"	"Medeah"	"
"Sea Serpent"	"	"Queen"	"	"Senator"	1857
"Metropolitan"	"	"Bilbao"	"	"Gaywan Bahri"	"
"Lima"	"	"Lancefield"	"	"Louis XIV."	"
"Shandon"	"	"Transit"	"	"Tage"	"
"Quito"	1852	"Albury"	"	"Duguay Trouin"	"
"Bogota"	"	"Gundagai"	"	"Thalia"	"
"Haiti"	"	"Fiery Cross"	1855	"Trebizond"	"
"Magdalena"	"	"Emerald"	"	"Light Ship"	"
"Cosmopolitan"	"	"Earl of Erne"	"	Engines for Robinow	"
"Spray"	"	Engines for East India Co. (2 pairs)	"		
"Miranda"	"			Engines for Hamburg (3 pairs)	"
"La Plata"	"				
"Laniston"	"	"Urgent"	"	"Lady Head"	"
"Olaf"	"	"Persia"	"	"Islesman"	"

and, although the vessels originally contemplated had been commenced, what was done was put aside, and in their place four vessels of 1,200 tons and 400 H.P. were laid down, to meet the extra cost of which vessels, Mr. Napier, at Mr. Cunard's request, got some of his friends, Messrs. Burns, Messrs. Thomson, and M'Connel, Mr. M'Iver, and a few others, to join him in the contract. From this originated the now celebrated Cunard Company, the great success of which was mainly due to the business character of Mr. Cunard, to the sound advice given, and to the honest, careful, and substantial work turned out by Mr. Napier, and to the superior manner in which the vessels were managed and officered by Messrs. Burns and M'Iver.

In 1853 Mr. Napier took his sons James and John into partnership; the former retired a few years after, when the business was carried on by Mr. Napier and his younger son. For a considerable time before his death Mr. Napier took very little active charge; but in the early stages of steam navigation, when so much of the success of steam companies depended on sound and correct views, he spared no pains, but went most carefully into all calculations for the size, power, carrying capacity, working expenses, &c., of

---

Name.	Year.
"Shadia"	1858
Gunboat (East India Co.)	”
Gunboat ”	”
Gunboat ”	”
Gunboat ”	”
Gunboat ”	”
Gunboat ”	”
"Emperor Alexander"	”
"Vladimir"	”
Hamburg Tug	”
"Aerolith"	”
"Victoria" (2nd)	”
"Douglas"	”
"Mercur"	”
"Lucifer"	”
Burmese Yacht	”
"Fifeshire"	”
"Malta" (2nd)	1859
"Jeddo"	”
"Shannon"	”
"Chevy Chase"	”
"Kedgeree"	”
"Oleg"	”
"Royal William"	1860
"Phœbe"	”
"Marathon"	”
"Hecla"	”

Name.	Year.
"Cormorant"	1860
"Racehorse"	”
"Serpent"	”
"Star"	”
"Eclipse"	”
"Lily"	”
"Torch"	”
"Plover"	1860
"Lee"	”
"Mullet"	”
"Penguin"	”
"Dart"	”
"Steady"	”
"Philomel"	”
"Snipe"	”
"Cygnet"	”
"Griffon"	”
"Sparrow"	”
"Chinsura"	”
"Foam"	”
"Orestes"	”
"Black Prince"	1861
"Scotia"	”
"Bristol"	”
"Dryad" (1st)	”
"China"	”
"Neptune"	”
"Parkhead"	”
"Hector"	1862

Name.	Year.
"Endymion"	1862
"Queen of Orwell"	”
"Clan Alpine"	”
"Wolf"	”
"Stirling Castle"	1863
"Warwick Castle"	”
"Rolf Krake"	”
"Roslin Castle"	”
"Pembroke Castle"	”
"Osman Ghazy"	1864
"Abdul Aziz"	”
"Ella"	”
"Charlotte"	”
"Emily"	”
"Caroline"	”
"Maude Campbell"	”
"Imogene"	”
"Florence"	1865
"Orkhan"	”
"Verona"	”
"Pereire"	”
"Ville de Paris"	”
"Agitator"	”
"Dryad" (2nd)	”
"The M'Leod"	”
"Malabar"	1866
Two Barges	”
"Vikingen"	”

the different schemes or lines that were brought before him; and to his honesty of purpose and perseverance in working out such details a great part of his success in life was undoubtedly due. Part, however, of his prosperity was owing also to his tact in getting the right people about him as managers and foremen, by whom, as well as by all with whom he had occasion to come into contact, he was held in the highest respect. He never could put up with bad or slovenly work, and if a thing did not please him, either as to design or workmanship, he did not hesitate to have it at once pulled to pieces and reconstructed.

Mr. Napier was a man of great common sense, very equable in temper, trying always to do his best, and, this done, leaving the result to a higher Power. Despite a rugged apprenticeship and laborious manhood, his handsome figure and courteous bearing to all proclaimed him one of Nature's noblemen. He was no public speaker, but always had a thoughtful word to say on almost every topic that might be started. He had a great dislike to hearing ill spoken of any one, and was, it may be said, without an enemy. From one of his teachers, Mr. Trail, of the Grammar School of Dumbarton, Mr. Napier imbibed a taste, while quite a young man, for the fine arts; and the collection of paintings and articles of virtu in his residence at West Shandon, on the Gareloch, was a continual source of enjoyment alike to himself and to his numerous visitors.

Name.	Year.	Name.	Year.	Name.	Year.
"Vaynol"	1866	"Mendez Nunez"	1870	"P. Caland"	1874
"Danae"	,,	"Lorne"	1871	"Pharos"	,,
"Lamont"	1867	"Rupert"	,,	"Amazonas"	,,
"Will o' the Wisp"	,,	"Garonne"	,,	"Arab"	,,
"Prompt"	,,	"Bustard"	,,	"Lily"	,,
"Hasty"	,,	"Kite"	,,	"Orisund"	,,
8 Troop Boats	,,	Ganges Canal Boat	,,	"Meiji Maru"	,,
"Washington"	,,	"Saga"	,,	"Opal"	1875
"De Buffel"	1868	"Galley of Lorne"	,,	"Sheldrake"	,,
"De Tyger"	,,	"Norden"	1872	"Moorhen"	,,
Steam Launch	1868	"Edinburgh Cas-		"Mary Ellen"	,,
"Audacious"	1869	tle"	,,	"Dunrobin Castle"	,,
"Invincible"	,,	"Windsor Castle"	,,	"Lille Belt"	,,
"Meteor"	,,	"Elizabeth Mar-		"Wild Swan"	1876
"Europe"	,,	tin"	,,	"Penguin"	,,
"Afrique"	,,	"Courland"	,,	"Northampton"	,,
"Hotspur"	1870	"Prince Edward"	,,	"Ingolf"	,,
"Elgin"	,,	"Galicia"	1873	"Canopus"	,,
"Lord of the Isles"	,,	"Modeste"	,,	"Clytie"	,,
"Valdivia"	,,	"Goethe"	,,	"Balmoral Castle"	,,
"Queen of the		"Schiller"	,,	"Fielden's Engines"	,,
Thames"	,,	"Hoboken"	,,	"Dublin Castle"	,,
"Cheops"	,,	"Plucky"	,,		
Siam Yacht	,,	"W. A. Scholten"	1874		

Mr. Napier was elected a Member on the 31st of March, 1840. He died at West Shandon on the 23rd of June, 1876, aged eighty-five years and five days, surviving by eight months his wife, to whom he had been married about fifty-seven years.

MR. WILLIAM OLIVER GOODING, the eldest son of Mr. William Gooding, of Queenborough, Kent, was born in the year 1837. At the age of sixteen he went with his uncle, Mr. James Hodges, to Canada, and during the three following years completed his education at the M'Gill College, Montreal. In 1856 he commenced the study of practical engineering in the drawing office and workshops of the carriage-building and locomotive departments of the Grand Trunk Railway of Canada. After this he was Assistant on the works at Gananoque, under Mr. R. Crawford, Assoc. Inst. C.E., and also upon surveys in Lower Canada under Mr. Rubridge. Subsequently he was posted to the Victoria Bridge, Montreal, then being carried out by Mr. Hodges for Messrs. Peto, Brassey, and Betts. Whilst there Mr. Gooding had sole charge of the construction of some of the cofferdams and piers, work of a difficult and responsible character, owing to the rapidity of the stream and to the short seasons during which the operations could be carried on.

In 1859 Mr. Gooding made an extensive tour of inspection of the great engineering works then in course of erection in the United States. On returning to England he assisted as a draughtsman in preparing for publication the well-known work of Mr. Hodges on the Victoria Bridge.[1] In August, 1860, he obtained an appointment under Mr. Mathew Curry upon the Algiers and Blidah railway, for which Messrs. Peto and Betts were the contractors. He had the entire charge of the construction of a section of 15 miles, which was completed and opened in two years. He was also engaged upon the preliminary surveys and arrangements for carrying out the Boulevard de l'Impératrice for the town of Algiers. In July, 1863, he became an assistant on the Dunaberg and Witepsk railway, then being carried out by Mr. Hartland for Messrs. Peto and Betts. There he had charge of 16 miles of line, including some important bridges and earthworks.

---

[1] *Vide* "Construction of the Great Victoria Bridge." By J. Hodges. Folio Plates. London, 1860.

In the spring of 1868 he, in conjunction with Mr. Prebble, Assoc. Inst. C.E., undertook the surveys of the Witepsk Kiew line of railway. In January, 1869, he took charge of the works of the Mediasch section, of 13 miles, of the East Hungarian railway, which embraced in its course several river diversions and stations, as also the yard for the construction of the contractor's plant. In the summer of 1870 he resigned this appointment, in order to assist Mr. Hodges in carrying out the extensive harbour and reclamation works at Callao, Peru. This was the last contract of the late Mr. Brassey, Assoc. Inst. C.E., and in importance and magnitude may be classed with any of the works undertaken by that gentleman. The works, which took nearly five years to complete, inclosed 52 acres, and provided accommodation for twenty-five to thirty large vessels, besides reclaiming an area of 13¼ acres of building ground, the whole of which was drained, paved, laid out in streets, and lighted with gas.

On the completion of the harbour in March, 1875, Mr. Gooding returned to England, and was elected an Associate while engaged upon the preparation for the society of a detailed description of the important works he had helped to carry out with such success and credit. Towards the close of the year, however, his health seemed suddenly to break up, and after a few weeks' illness, he died on the 17th of December, 1875, when only thirty-eight years of age, regretted by a circle of friends such as is acquired by few men of his age.

SIR WILLIAM JACKSON, Bart., was born at Warrington, in Lancashire, on the 28th of April, 1805. He was the seventh son of Mr. Peter Jackson, who practised there successfully as a surgeon, and of Sarah, daughter of Mr. Henry Mather. Sir William's mother had, at the time of her marriage, considerable wealth, but her fortune being dissipated by mismanagement and dishonesty, she found herself at her husband's death, in 1810, with a large family of children and but small means. Soon afterwards a removal was made to Liverpool, which seemed to offer better prospects for placing out a family than the comparatively small town of Warrington. William was at first sent to a merchant's counting-house, and as the custom then was, took weights at the ship's side from six in the morning till late at night; but he thus obtained an insight into the detail of commercial life which he

never lost. Before long, however, the firm by whom he was employed gave up business, and the boy, for such he still was, without consulting any one, apprenticed himself to Mr. Hunt, who carried on business in Church Street, Liverpool, and in whose service he succeeded in winning general esteem. On finishing his apprenticeship, he at once started on his own account, and though only twenty-one years of age, his family were glad enough to trust the means they had left to his care. A few years sufficed to make him known as a man of great enterprise and judgment, and to induce Messrs. John and William Hamilton (who were possessed of what was then looked upon as a considerable capital) to join him and his brother in partnership. The firm of Hamilton, Jackson, and Co. had a short but brilliant career. One of the Jackson Brothers had visited the West Coast of Africa, whence he brought home accounts of possible barter, and even hopes of permanent trade. This resulted in ship loads of Manchester and other goods being exchanged for palm oil, ivory, and gold dust, to the great advantage of the Liverpool house. Competition was not so warm then as now, and by 1841 the firm was dissolved, each partner taking with him a haudsome fortune. Afterwards, in a maiden speech in the House of Commons, Sir William referred to his commercial relations with the West Coast of Africa, and asserted then, as indeed he did on all occasions through life, that the slave trade had received its greatest blow by the establishment of trading factories, and that its ultimate suppression would be best served by the development of commerce.

Mr. Jackson married, in 1829, Elizabeth, daughter of Lieutenant Hughes, a half-pay officer, who held some post under the Corporation of Liverpool. To the careful devotion and unvarying attention of this lady he owed much of his success in life; whilst her genial manner and graceful hospitality made his house a rendezvous for a rapidly increasing circle of friends. Shortly after his marriage he went to reside at Birkenhead, and at once appreciated its future, taking an active part in the government and politics of this new town. He was soon chosen one of the Improvement Commissioners, and while the place was in its infancy, he joined the late Mr. Brassey, Assoc. Inst. C.E., in purchasing land, in developing which, by laying out streets and building houses, he expended large sums of money. He was an active promoter of the Chester and Birkenhead railway, and was at one time Chairman of the company. It was in connection with this enterprise that he met the late George and Robert Stephenson, the acquaintance ripening into friendship, and con-

tinuing unbroken till they died. At the same time he established the gas and waterworks for the town—the latter were laid out by George Stephenson—and at a later period he projected the magnificent public park there, which was carried out under the personal direction of the late Sir Joseph Paxton, Assoc. Inst. C.E. Mr. Jackson was also one of those who took an active part in the projection and formation of the Birkenhead Docks. The family of the late Mr. John Laird, M.P., jealously claimed the original conception for Mr. William Laird, the founder of their family, and Mr. Jackson himself admitted that claim; but that was years before the scheme was practicable, and certainly Mr. Jackson had as large a share as any one in the labours which actually carried it into execution. As an instance of Mr. Jackson's courage and determination, the purchase by him of the Woodside Ferry may be noted at a time when it "had to be sold," and the transfer by him of this purchase to the township, without profit, when the township saw they had lost a chance. This ferry has proved a lucrative property for the town, and had Mr. Jackson retained it, would alone have secured for him a large fortune.

On retiring from commerce in 1841, Mr. Jackson invested a large part of his fortune in the Birkenhead enterprises, and the fact that he had capital of his own probably enabled him to weather the storm which in 1847 proved fatal to many of his competitors. Although all the anticipations of some of the earlier founders of Birkenhead may not have been realised, still there is the town (which when Mr. Jackson went there had but fifteen hundred inhabitants) with its sixty thousand souls, its streets, its dock, its railways, its parliamentary representation, and its assured future. With this result Sir William Jackson's name will ever be closely connected.

But Birkenhead after all was the field of part only of Mr. Jackson's career, and of only half his work. He was directly interested, with the late Mr. Brassey, in constructing the Victor Emmanuel, the Maria Antonia, the Maremma, and many of the other principal railways in Italy, and also in the Grand Trunk railway of Canada. When the Northern railway of Canada was *in extremis* Mr. Jackson came forward and, jointly with Mr. Brassey, reconstructed it, taking payment to the extent of £200,000 sterling in bonds which were at the time unmarketable, and had the satisfaction of seeing his estimate of the value of this undertaking justified by the result. Mr. Jackson was one of the original proprietors of "The Daily News," a journal which was designed to inaugurate a cheap press, and which has fulfilled its intention,

though at the expense of the original adventurers. His courage and determination led him to despair of nothing, and his friends not unfrequently joked at his fondness for a doubtful investment. In this spirit he joined the board of the Great Eastern Steamship Company when an attempt was made to popularise it; and at a later period he instilled hope into the despairing shareholders of the Imperial Mercantile Credit Company while in liquidation, and by his example and force of will showed them how to save their own property from the ruin for which neither he nor they were responsible.

Sir William Jackson was associated with many other enterprises. He was essentially a Producer. Safe income-yielding investments had no charm for him; as fast as he made money he put his earnings into something which would, in however small a degree, increase the wealth of the world, and thus he earned the praise, that no one was ever the poorer for any money he made.

For many years he was a partner in, and at his death he was the sole owner of, the Clay Cross Coal and Iron Works in Derbyshire. This concern was started by George and Robert Stephenson in connection with the late Lord Wolverton, Mr. George Hudson, Sir Joshua Walmsley, Sir Morton Peto, and others. Gradually all their interests were acquired by Mr. Jackson. He was also the principal owner of the Bettisfield Colliery at Bagillt in Flintshire.

In 1847 Mr. Jackson entered Parliament as member for Newcastle-under-Lyne. He continued to represent this borough without interruption till 1865, when he was returned without opposition for the Northern Division of the county of Derby. By the Reform Bill of 1867 that division was subdivided into the Eastern and the Northern. Mr. Jackson elected to stand for the Northern division. At the last moment an opposition sprang up, and the wave of Conservative reaction, which had even then plainly been discerned, flowed into Glossop and the manufacturing districts around, and lost him the seat by a small majority. Shortly after this his health completely failed, and he spent the rest of his days in retirement. Notwithstanding much suffering, he retained his cheerful disposition, and kept up his interest in public matters unimpaired; but in January 1875 Lady Jackson died, and from that time he waited quietly for his own end, which came suddenly on the 30th of January, 1876, when he was in his seventy-first year.

In 1869 he was created a baronet, in recognition, as Mr. Gladstone told him in announcing the distinction, of the eminent services he had rendered to the commercial and manufacturing

interests of the country. Sir William Jackson was a magistrate and deputy-lieutenant for the county of Chester. In politics he was a consistent and hearty Liberal, of what was in his day considered rather an advanced type. But his political temperament was always controlled by good common sense, and he was a thoroughly trusted party man. He did not often speak in Parliament, but when addressing the House was always, notwithstanding some provincialisms which he retained to the last, listened to with attention.

Sir William Jackson was elected an Associate on the 7th of December, 1852.

MR. ELIHU HENRY OLIVER was born on the 8th of November, 1839, at Newcastle-on-Tyne. His early education was pursued at the school of the Society of Friends at Ackworth, Yorkshire. In June 1858 he was articled for five years to Mr. Matthew Liddell, to learn the profession of a Mining Engineer, and he availed himself of the opportunities thus enjoyed. After leaving Mr. Liddell he went to China, and arrived at Shanghai in November 1864, accepting a situation at once as an assistant to Mr. F. H. Knevitt, an architect there. In August 1865 he was appointed Assistant Engineer under the late Mr. John Clark, M. Inst. C.E., at that time Engineer to the Shanghai Municipal Council; in February 1866 he became Surveyor to the Council, and in November 1868 Engineer, which post he held till his death. In these latter positions he had sole charge of the engineering works in the foreign settlements (excepting the French), the population of which in 1875 was seventy thousand, of whom, however, only about three thousand were foreigners, not including the shipping. He carried out successfully the main-drainage scheme of the settlements, which was difficult owing to the flat and low nature of the ground; and although necessarily expensive, the sanitary improvement of the town has since been very marked. He designed and erected several iron and wooden bridges, landing-stages with floating pontoons, buildings, &c., and formed and made several important roads in the town and its vicinity. But, possibly, the greatest improvement was filling up a large portion of the foreshore of the Shanghai Bund, and converting it into a public garden, which he laid out with great taste. The new wooden "Garden Bridge," across the Soochow Creek, built from his designs, was formally

opened to the public in August 1874, and is well spoken of. He also designed, as his contribution, the Seamen's Church at Shanghai, a simple, appropriate, and pretty building, opened in 1864, of which a drawing appeared in the "Illustrated London News" at the time. In 1872 he drew up three schemes for the supply of water to the district under his charge, but although these met with general approval from the ratepayers, the estimated cost was considered to be too great for so young a settlement. Early, however, in 1875 the water-supply question was again agitated, and, following out suggestions then made, an amended scheme, on a smaller scale, was prepared, which has been favourably reported upon by Mr. Hawksley, Past-President Inst. C.E. The quantity of water proposed to be supplied is 1,000,000 gallons per day, at an estimated cost of upwards of £100,000.

Although the post of Engineer to the Municipality of Shanghai may not afford much scope for professional ability, yet Mr. Oliver carried out what he had to do so well that he earned for himself a good name. Straightforward and a thorough man of business, he was much respected, and in him the municipality lost an energetic and a capable servant, to whom the foreign community in particular were much indebted. In private life he was esteemed for his open-handed generosity, his liberal hospitality, and his unaffected good nature—qualities which made him a valued friend and a trusted adviser. Mr. Oliver was elected an Associate on the 6th of February, 1872, and he died at Shanghai on the 16th of January, 1876.

MR. GEORGE POTHECARY was born on the 1st of October, 1841, at Munslow, Salop, where his father practised as a surgeon for nearly twenty years. In the year 1852, on his father removing to the South of England, he was sent to Sherborne Grammar School, entering the house of the head master, the Rev. H. D. Harper, where his amiable disposition rendered him a general favourite with his companions, and secured him the esteem of the masters. On leaving school he chose the profession of a Civil Engineer, and was articled, in 1859, for three years to Mr. W. Humber, Assoc. Inst. C.E. At the expiration of his pupilage, failing to secure employment in London, he entered a college at Chester to prepare for a competitive examination for an appointment in the Indian Public Works Department, which he passed in

July 1863, standing sixth on the list. On reaching Calcutta he was appointed Probationary Assistant Engineer on the second division of the Grand Trunk Road at Shergotty, and was engaged in the erection of some large bridges. On this division he remained for about three years, being gazetted Assistant Engineer, 2nd grade, in September 1864, and Assistant Engineer, 1st grade, in October 1865. At the latter date he was appointed to the Lower Assam Division, where he had charge of a district of 20,000 square miles, but was obliged to return to Calcutta owing to an attack of fever. In February 1867 he passed the examination in the native languages, by the higher standard, and was posted to the Mahanuddy Division; and later in the same year was promoted to Executive Engineer, and was transferred to the Pooree Division. On the 1st of March, 1869, he was appointed to the charge of the Southern Cuttack Division, and afterwards to that of the Hooghly River Division. Early in 1870 he was transferred to the Circular and Eastern Canals Division, and was selected as Assistant to Mr. Leonard, M. Inst. C.E., in carrying out the important works for the improvement of the Port of Calcutta, the commencement of the fine works for facilitating the import and export of goods. In the same year he officiated for seven months, during the absence of Mr. W. Clark, M. Inst. C.E., as Engineer to the municipality of Calcutta, and took the entire control of the drainage, road, and water works; and subsequently, in 1871, he was again employed by the Justices of Calcutta in making investigations as to the drainage of that city. After a visit to England, he, in the middle of 1871, was appointed Assistant to the Chief Engineer of Bengal (Mr. H. Leonard), and Assistant Secretary to the Government of that province. On the outbreak of the famine in Berar, early in 1874, he was sent to Mozufferpore as special Superintending Engineer of the Sarum, Champarum, and Tirhoot districts, under Sir Richard Temple, although at the time only a second-class Executive Engineer. The arduous labours there incurred told upon a constitution never strong, and his health became seriously impaired. For his management of the famine relief works he received the commendation of the Government of Bengal. He paid a short visit to England in 1875, returning to Calcutta to resume the duties of his appointment as Assistant to the Chief Engineer, in September; but was obliged finally to leave India at the end of February 1876. He died at Paris, of disease of the heart, while on his way to England, on the 17th of May, 1876, having only been elected an Associate on the 13th of January, 1874.

Though without opportunity of doing any very conspicuous work, Mr. Pothecary saw much and varied service, and he was held by his superior officers, as well as by his contemporaries, to be one of the ablest of those selected by competitive examination, and to be one of the most promising men in the department. Fond of the profession, of easy and polished manners and refined taste, endowed with a good memory, well read in the current literature of the day, with a good voice and a correct ear, he was a favourite not only with the members of his own department, but also with the other officers of Government with whom he had to deal. His geniality, amiability, and kindness of heart endeared him to many a home, and he was as much liked in private life, as he was esteemed and respected in his professional capacity. The Royal Indian Engineering College at Cooper's Hill is indebted to his exertions as Secretary to the Committee which inaugurated and successfully established the scholarships given by the Indian Civil Engineers to the College.

MR. RICHARD STEVEN ROPER, son of the late Mr. Thomas Roper, of Ulverston, was born on the 20th of February, 1835. He studied under Dr. Muspratt in the School of Chemistry, Liverpool, from whom he received, in 1852, a certificate in praise of his diligence, progress, and accuracy in analyses and assays. He afterwards became a student at the School of Mines, London, and on the 20th of January, 1855, he received a first-class certificate. After leaving the School of Mines, he was engaged under the late Mr. Ebenezer Rogers at the Abercarn Collieries, Monmouthshire, where, in addition to attending to the general routine of colliery work, he was much occupied in the laboratory. In 1856 he was employed at Dudley under Mr. Samuel H. Blackwell (a brother-in-law of Mr. Ebenezer Rogers), and in 1857 he entered the service of the Ebbw Vale Company, Monmouthshire, and was engaged at their Ebbw Vale and Victoria Iron Works, and also at their Pontypool works. Shortly after this, in conjunction with Mr. George Claridge, of Dudley, he took out a patent for an improved mode of manufacturing coke, and wrote a useful pamphlet on the desulphurization of coke. In 1859 he entered into partnership with Mr. John Lawrence, of the Cwmbran Iron Works, Monmouthshire. In 1856 he was elected a Fellow of the Geological Society of London; in 1859, a Fellow of the Chemical Society; in April 1872, an

Associate of the Institution of Civil Engineers. He was also a member of the South Wales Institute of Engineers and of the Iron and Steel Institute. He died in London on the 7th of April, 1876, after an illness extending over about three years.

MR. PETER SOAMES was born at East Greenwich in the year 1830. He was educated for three years (1847–9) in the Applied Science Department, King's College, London, of which he became an Associate in 1849, and took Honours at the London University. Having acquired a taste for mechanics, through frequent visits to the works of one of his brothers, an extensive manufacturer, he was articled for three years (1849–52) to Mr. Albert Robinson, of the late firm of Messrs. Robinsons and Russell, of Millwall. In 1852 he accepted an appointment to take charge of the erection and management of sugar machinery and plant on several estates in Jamaica. The effects of the climate necessitated his return to England, and in 1855 he commenced business as a mechanical engineer on his own account, at the Morden Iron Works, East Greenwich, and was chiefly occupied in the design and construction of steam-engines, sugar machinery, and mill work, introducing several improvements in sugar-cane mills, and in sugar-boiling and treating apparatus, upon which class of machinery he was frequently consulted. Finding this field of occupation too limited, in 1864 he went to Siam, where he erected a large sugar factory for the King, which gave great satisfaction. He suggested various public works of importance, such as lines of submarine and land telegraphic communication, which he worked out in a practical way; but unfortunately the climate did not agree with his constitution, for he was stricken down by fever, which prostrated him for a long time.

Amongst other things to which Mr. Soames devoted himself was the perfecting of the wire-rope and telegraph-cable-making machinery of Messrs. William and Archibald Smith, for Messrs. Glass and Elliot, and others. This brought him in contact with Mr. William Smith, Assoc. Inst. C.E., with whom in 1867–8 he became associated in connection with the "Artizan" engineering journal, at first as assistant editor and manager, and in 1870 he became the proprietor of that journal, which he continued to conduct until early in 1872. In the same year Messrs. Spon published for him "A Treatise on the Manufacture of Sugar from the Sugar Cane." Mr. Soames was an excellent mathematician and a good

mechanic; his analytical powers and ability to deal with scientific facts were tested in many ways, especially in numerous heavy cases of litigation respecting mechanical inventions.

He was an agreeable companion, possessed of good natural ability and varied experience, refined and extended by study and observation. He was elected an Associate on the 6th of December, 1870, and he died at Hastings on the 1st of February, 1876, in the forty-seventh year of his age.

MR. GEORGE THOMPSON was born at Greenwich on the 26th of March, 1839. In 1849 he was sent to a school near Stuttgart, which he left in 1852, continuing his studies at Dr. Knightley's, in the neighbourhood of London, until 1854. From 1855 to 1857 he served a pupilage under Mr. W. L. Arrowsmith, superintendent of Government works at Malta, and was put on the engineering staff of the gas-works in that island. He returned to England in 1857, and soon afterwards was engaged for one year as a draughtsman at the locomotive works of Messrs. Beyer, Peacock and Co. In 1858 he left for South America, with the object of allying himself with a brother who was occupied in mercantile pursuits, but after a time this idea was abandoned, and in September of the same year he joined the staff of the Asuncion and Villa Rica railway in Paraguay, under the late Mr. George Paddison, M. Inst. C.E., becoming in 1862 one of the Assistant Engineers to Messrs. Burrell and Valpy, MM. Inst. C.E., the then Engineers in Chief of that railway. Although a mere youth, he was at this time considered to be one of the best Guarani scholars, besides speaking fluently five or six other languages. The war between Paraguay and the allied forces of Brazil and the Argentine and Oriental Republics having broken out in the latter part of 1864, Mr. Thompson, in 1865, offered his services as a military engineer to the Paraguayan President, Don Francisco S. Lopez, and this offer being accepted, he joined the army in the June of that year, and took a prominent part in the war until the end of 1868. He chose many of the positions and designed and constructed many of the defences during the war, and his achievements will always live in South American history, as he held at bay the fleet of the allies for several weeks, whilst in command of a river battery at Angostura, a few miles below Asuncion. Although obliged to capitulate, the allies allowed him all the honours of war, as he refused to surrender at discretion.

The fall of Angostura was virtually the end of the war. Previous to this Mr. Thompson had been promoted to the rank of lieutenant-colonel in the Paraguayan army, and had received from President Lopez the decoration of "Knight of the order of merit" (*Caballero del orden del merito*). A few months were passed in England in 1869, during which he wrote "The War in Paraguay," a work which gives a very faithful account of the campaign. Mr. Thompson then returned to South America and married a Paraguayan lady, who, with three children, survives him. In 1870 he proceeded to Cordoba, in the Argentine Confederation, where he was appointed President of the Topographical Department, and made and published a map of the province. He resigned that appointment in September 1871, and subsequently became the Engineer and Manager of the Asuncion and Villa Rica railway in Paraguay, which he gave up about two years ago, but remained in that country to the time of his decease, which took place at Asuncion in March 1876, after a lingering illness.

He was only elected an Associate on the 4th of March, 1873.

MR. JOHN HOOPER WAIT was born at Stevenage, in Hertfordshire, on the 25th of July, 1847. His education was conducted at Cheltenham Grammar School; but at the early age of sixteen he joined his parents in India, with whom he remained until commencing his pupilage under Mr. C. D. Roberts, one of the Resident Engineers on the Madras railway. In 1864 he was placed on the staff of the Madras Irrigation and Canal Company, and in the following year became an assistant to the late Mr. East, M. Inst. C.E., Executive Engineer of the Nellore Division, remaining in that position until the completion of the Nellore scheme in 1867, when he was employed under the late Mr. A. J. Dodson, M. Inst. C.E., one of the other Executive Engineers of the same company, as well as under Mr. H. O. Cotton. During the greater part of 1867 he was special Assistant Engineer in the construction of a line of telegraph. In 1868 and part of 1869 he was Assistant Engineer under Mr. Arrott Browning, M. Inst. C.E., Executive Engineer in the construction of irrigation works. For nine months in 1869 he was again engaged under Mr. East on survey work for large reservoirs in the Mysore District. Subsequently he was occupied on the Mysore State Railway Survey, and towards the end of 1871 he rejoined Mr. East, and assisted in the construction of the

Bhownuggur Waterworks, of which he had charge as State Engineer from 1872 until his death, which occurred on the 27th of June, 1876. At the end of 1872 Mr. Wait visited England, and during a short furlough of three months took steps for his admission into the Institution, having been elected an Associate on the 4th of February, 1873. He was always spoken of in the highest terms by those under whom he served, and was regarded as a man of more than ordinary intelligence and as an exceedingly agreeable companion. A brave and most unselfish act, done at the risk of his life, ought to be recorded. When the prisoners in the Bhownuggur jail mutinied in 1872, Mr. Wait led an attack upon them which put an end to the outbreak. The State acknowledged the service he had rendered by presenting him with a sword and ring.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

On the Transmission of Motion by 'Teledynamic Cable' and by Belt and Pulley. By L. VIGREUX.

(Annales du Génie Civil, 2nd series, vol. v., pp. 171, 233, 314.)

'Teledynamic cable' is the name applied by the Author to the endless wire rope as used for the transmission of power from one shaft to another. He defines his problem by supposing that a shaft, A, receives from one or more prime movers an energy equal to 80 HP., and has to transmit this to another shaft, B, which latter is at a horizontal distance of 875 yards, on a level 13 feet higher, and is inclined to A at an angle of 10°. In certain cases B also receives energy from a steam-engine of 20 effective HP., whose main shaft makes 50 revolutions per minute, is 26 feet distant from B, and transmits its power by a pair of pulleys and a leather belt. The transmission between A and B is effected by a wire rope passing over intermediate sheaves; and the problem is to calculate the work lost by friction, &c., in this transmission, and to compare its effect with that of a line of shafting and two pairs of bevel wheels, which would be the alternative method.

The Author begins by neglecting friction on bearings and weight of rope. He afterwards gives a complete investigation taking in these quantities, but assuming, in order to facilitate calculation, that the curve of the rope is a parabola and not a catenary. He at the same time furnishes some practical rules, based partly on experiments, and partly on experience in the working of the 'teledynamic system.'

Section of belt or rope.—The Author considers that the working strain in these cases should not exceed, for a leather belt, 212 lbs. per square inch (or 150,000 kilogrammes per square mètre), and for a wire rope, 7,111 lbs. per square inch (or 5,000,000 kilogrammes per square mètre). As belts are made of leather about $\frac{3}{16}$ inch (5 millimètres) thick, and it is not generally convenient to have them more than 12 inches (300 millimètres) wide, there is a limit beyond which the tension on a belt must not be carried. Should the tension on a proposed belt be found, on calculation, to exceed this limit, the difficulty may be got over in two ways: 1. The speed may be increased; when, the energy remaining the same, the tension is of course diminished. 2. The size of the

pulley may be increased; when the tension acting at a greater arm is of course smaller in amount.

Leather was originally the only material used for belts, but of late gutta-percha, india-rubber, and a sort of india-rubber cloth have been employed for the purpose. Experiments by M. Tresca on these materials show that leather is much stronger than gutta-percha or india-rubber, but that the india-rubber cloth is the strongest of the four; this last has also the advantage that it stretches very little, and can be made of large dimensions.

In the case of wire ropes, a table is given showing the different diameters found in commerce, the weight per lineal mètre and the breaking strain of each, so as to facilitate the selection of the proper size of rope for any particular purpose.

It is remarked that, for wire ropes, the driving span should always if possible be the under, not the upper one of the two: by this arrangement the two spans are brought nearer together when at work, instead of farther apart; they embrace a larger arc on the pulleys, thus adding to the friction, and the rope is kept as far as possible from the ground.

Returning now to the teledynamic problem defined at the commencement, four modes are mentioned by which the shafts A and B may be connected by a cable. These are: 1. To place near each of the main shafts an auxiliary shaft, connected with it by bevel gearing. These auxiliary shafts are parallel, and may therefore be worked by ordinary pulleys and wire cable. 2. To place between A and B two auxiliary shafts; one parallel to A, and connected with it by a cable; the other parallel to, and similarly connected with B. These shafts are close together, and connected by bevel gearing. 3. To use a single cable, passing at one end round a pulley on A, and at the other round a pulley on B, but each span of which has its direction changed in the middle of its course by passing round a horizontal pulley. 4. To dispense with auxiliary pulleys, and use only supporting sheaves about every 100 yards: these are placed at the angles of a regular polygon, whose extreme sides are perpendicular to A and B respectively, and each of them is so inclined as to be in the plane of the two tangents to the respective lengths of the cable, which meet at that point. This last solution is that preferred by the Author, and equations are given by which the required polygon may be traced out, and the inclination of the intermediate pulleys determined.

The dimensions of the shafts and pulleys in the various cases are calculated by formulæ derived from other works of the Author. The weights of these pulleys and shafts being known, and the tensions on the two spans, the resultant pressure on the bearings of any of these shafts is easily found. The velocity of the cable is also supposed to be known, and therefore the number of revolutions of the shaft. The energy lost by friction on the bearings in this case can thus be calculated, as being equal to the resultant pressure on the bearings × the space turned through by the shaft per second × the co-efficient of friction, which for bearings con-

tinuously lubricated may be taken at 0·05. The same calculations being made for all the other bearings, and the results added together, the total loss due to friction by the working of the cable is ascertained. In the problem under discussion this loss is calculated to be somewhat less than 5 per cent. of the whole power applied. This is now to be compared with the loss of power that would result if the means of transmission were a line of shafting. It appears that if the diameter of a shaft is strictly proportional to the force of torsion, the energy lost in friction is simply proportional to the energy transmitted, so that the speed of the shaft is so far a matter of indifference. But as the cost of construction is nearly proportional to the weight of the shaft, a light, quick-running shaft is generally to be preferred, provided it is not so thin as to bend under the strain of the various belts which it actuates. A speed of 250 revolutions per minute is adopted in the present case. The shafting is supposed to be in lengths of 25 feet, and to diminish in diameter from the driving to the driven end, as the power is gradually taken off from it by the friction on the intermediate bearings. The diameter is supposed to diminish by $\frac{3}{16}$ inch ($\frac{1}{2}$ centimètre) at a time; and commencing with a diameter of $3\frac{1}{2}$ inches (9 centimètres), it appears that this may be reduced to $8\frac{1}{2}$ centimètres after a length of 296 mètres, then to 8 centimètres after a further length of 320 mètres; this diameter continuing for the remaining 184 mètres of the total length of 800 mètres (875 yards). The energy expended in friction of bearings through this distance is calculated to be not less than 37 per cent., as compared with 5 per cent. for the cable. The cost of the shafting would also be about three times as great as that of the cable and supports.

The supports for the intermediate pulleys of the cable consist of two pillars of masonry about 2 feet apart, having on the top plummer blocks for the pulley shaft carrying the upper span, and having wall boxes built into them to take the bearings of the pulley carrying the lower span. Where the foundation is bad, *e.g.* thick peat, the masonry may be founded on piles, or on a large bed of concrete laid at the bottom of the excavation, or on a mass of clean river sand, placed in layers, so as to form a truncated pyramid, whose sides slope at an angle of about 45°. On this plan the Author has laid the foundations of an accumulator weighing, with its masonry pedestal, about 200 tons. The base of the pedestal in this case was $11\frac{1}{2}$ feet square, and the mass of sand was 20 feet square at the bottom and 4 feet high. This mode of foundation, however, can only be used where there is no danger of the sand being disturbed by the filtration of water washing it into the surrounding ground.

It has generally been considered that 130 feet is the least distance to which transmission by cable can profitably be applied; within this distance the cable is subject to considerable oscillations, which occasion much loss of energy, and also rapidly deteriorate the metal. The Author, however, had occasion to use

a cable for a distance of only 82 feet, and he found that this cable acted perfectly during rain, but was subject to large oscillations in dry weather. The Author considers these to be due to the heating of successive parts of the cable, by the extension produced in passing from the lower tension of the trailing to the higher tension of the leading span. At any rate, in the case described, the oscillations in dry weather were completely cured, by keeping the cable continually sprinkled with cold water.

W. R. B.

On the Transmission of Motive Power by Wire Ropes.

By A. ACHARD.[1]

(Annales des Mines, vol. viii., p. 229.)

A description is first given of the transmission of motive power by wire ropes at Oberursel, near Frankfort-on-the-Main, constructed under the direction of M. D. H. Ziegler. At this place there is transmitted to a manufactory the motive power of a fall of water 263 feet in height, and discharging from 12 to 31 gallons per second. The fall of water is utilised by a turbine geared with a driving pulley making 114½ revolutions per minute. The crown of the turbine is 7 feet 3 inches in external diameter, and 3½ feet in internal diameter, with a height of 6·69 inches. The total distance to which the power is transmitted is 3,153 feet, which is divided into eight spans, the first seven being of 393·7 feet, and the last 397 feet. The fall in the different spans varies from 30·5 feet in the first to 11·68 feet in the sixth, the total fall from the shaft of the driving pulley to that of the last following pulley being 145·65 feet. The pulleys are all 12·3 feet in diameter, and each 25 cwt. in weight, including the shaft. The cable is composed of six strands, consisting of six wires, 0·06 inch in diameter, the sectional area being 0·098 square inch, and the strain due to flexure = 17·64 lbs. The limiting tension allowable being 39·68 lbs., there is an effective working tension of 22·4 lbs. per square millimètre of section, corresponding to an effective tension of the whole cable of 1,400 lbs. at the pulleys.

The velocity of the cable is 73·8 feet. The HP. capable of being transmitted is thus seen to be 94·1, which is about the ordinary amount of available power developed by the turbine.

The grooves of the pulleys were first lined with gutta-percha, but not finding this durable, M. Ziegler had it replaced by leather.

Schauffhausen.[2]—At this village, situated on the right bank of

---

[1] The theoretical (first) part of this article, by the same Author, will be found in the Minutes of Proceedings Inst. C.E., vol. xli., p. 323. Also "Theory of the Transmission of Power by Ropes," by H. Resal, Minutes of Proceedings Inst. C.E., vol. xxxix., p. 406.

[2] For a further account of these works, and details of the cables by Kronauer, see "Schweizeriche Polytechnische Zeitschrift," 1867.

the Rhine, a few miles above the well-known falls, works were carried out in 1862–64 to utilise the hydraulic power of the river. The dam was built across the Rhine, on an uneven bed of rock, traversed by numerous fissures, and consists of round iron piles 4 inches in diameter, to which a cast-iron skin is securely bolted. On the skin are cast flanges for the attachment of timber shores to enable the dam to resist the force of the current. The water power is utilised by three Jonval turbines, placed in a line parallel to the axis of the river, somewhat nearer the left bank than that on which the town is situated. The turbines transmit their power to a shaft by bevel wheels capable of being thrown out of gear, so that one or more of them may be used at the same time. Their net united work amounts to 740 HP., of which 476 HP. are at present utilised; 150 HP. being transmitted, part to the left bank directly by shafting, and part to the right bank by a small cable crossing the river a little below the main cables, which transmit the remaining 326 HP. to the manufactories in the town. There are three intermediate pulleys between the turbine and the last following pulley, dividing the distance into five spans of the respective lengths:—

1st span	386 feet
2nd „	378 „
3rd „	333 „
4th „	456 „
5th „	444 „

The pulleys are 14 feet 9 inches in diameter, mounted in pairs on the shafts, at a distance apart of 4 feet 11 inches. The two cables are identical, and are composed of eight strands each, consisting of ten wires, 0·0721 inch in diameter, or about No. 16, B. W. G.

The tension necessary for the transmission of 326 HP. is 5,807 lbs., the velocity of the cable being 61·87 feet. Each cable is made strong enough, in case of breakage of the other, to transmit the whole of the available power of the turbines.

The following table gives the amount of HP. leased, and the receipts for the years 1867–74:—

Year.	HP. leased.	Receipts. £. s.
1867	120	344 0
1868	148	584 15
1869	178	732 3
1870	252	831 2
1871	290	1,215 12
1872	334	1,515 4
1873	347	1,656 5
1874	478	2,311 7

Fribourg.—At this town, situated on the Saane, a branch of the Aar, a company was formed in 1869, called "Société générale suisse

des Eaux et Forêts," for the supply of the town with hydraulic power from the Saane. A dam 98½ feet in width at the bottom, and 20 feet at the top, constructed entirely of hydraulic-lime concrete, was thrown across the river, thus obtaining a fall of about 34 feet 6 inches, and converting the valley above into a capacious reservoir, affording a large supply of water during times of drought. There are two Girard turbines, one for the water supply of the town, and the other to develop the power transmitted to the manufactories. This second turbine has a net HP. of 300, which is transmitted to a point at a horizontal distance of 2,510 feet, and at the height of 269 feet above the driving pulley of the turbine. The distance is divided into five equal spans of 502 feet, the total rise being equally subdivided, so that the difference of level between each pulley and the next is 53·8 feet. The pulleys at all the stations are 14 feet 9 inches in diameter; the cable weighs 1·5 lb. per lineal foot, and is composed of ten strands, each of nine wires 0·070 in diameter, or about No. 15, B. W. G. The pulleys make 81 revolutions per minute, which corresponds to a velocity of 65 feet per minute of the rope. Thus the tension necessary to transmit 300 HP. is 5,198 lbs.; the sectional area of the rope being 0·356 square inch, or a tension of 6 tons 10·6 cwt. per square inch. The tension at any point in the catenary is equal to the weight of a piece of rope of the length of the distance of the point of rope under consideration from a certain straight line. Thus the difference of the tensions at the two extremities is equal to 1·5 × 53·8, or 80·7 lbs., and the tension at the upper pulley is equal to 5,198 + 80·7, or 5,278·7 lbs.

A. T. A.

Comparison between the Cost of Hemp Ropes, Wire Ropes, and Iron Chains, in relation to their Strength.

By Karl v. Ott.

(Technische Blätter, vol. viii., p. 76.)

The Author, in introducing this subject, says the first step to be taken in the investigation is to determine the working capacity of each form of rope, be it hemp, wire, or chain, and then to compare the cost of each under equal capacities of bearing and breaking weights, taking the pound as the unit of force, the inch as the unit of length, and the square inch as that of the cross section.

Hemp Ropes.

The bearing capacity of a hemp rope generally increases in proportion to its thickness, the number of its strands, the slackness with which they are twisted, and the quality of the hemp. In

order to obtain the necessary compactness, the single threads are twisted into strand until they have lost about one-fifth of their original length. The threads, by twisting, undoubtedly lose a part of their capacity of bearing in proportion to the increase of tension and of the angle of twisting; nevertheless they become more durable, and obtain that tightness and solidity which are necessary to fit them for use.

To illustrate the influence of the angle of twist on the strength, it may be stated that, in a series of trials, ropes of 0·866 inch in diameter, of exactly the same quality of material, whose threads had been shortened by twisting one-fifth, one-fourth, and one-third of their original length, broke respectively with a load of 6,834 lbs., 5,335 lbs., and 4,519 lbs.

The form of rope quoted below is that called the patent hemp rope of the usual description. The Author remarks that dry ropes are firmer than those that have been wetted or tarred, because the threads in the latter case become thicker and shortened by the penetration of fluid, and are subjected, consequently, to so much greater a tension that they lose about 25 per cent. of their power. Taking everything into consideration, the strength of a rope varies between 7,111 lbs. and 11,378 lbs. per square inch, so that with one-sixth of the breaking weight as a safe load 1,422 lbs. per square inch may be adopted as a basis.

The effective cross section is about nine-tenths of the area of the circle of a patent hemp rope; therefore the absolute capacity of bearing, P, of a hemp rope of the diameter d (in inches), taking six times the breaking weight as the safe load, is obtained from the equation

$$P = 0 \cdot 9 \frac{1422\, d^2 \pi}{4} = 1005\, d^2 \text{ lbs.} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The weight, G, of a hemp rope per lineal foot

$$\left.\begin{array}{ll}\text{In a dry and untarred state is} & G = 0 \cdot 2812\, d^2 \\ \text{In a wet and tarred state,} & G = 0 \cdot 3376\, d^2\end{array}\right\} \quad . \quad (2)$$

The following table for the use of hemp rope is given:—

d. Diameter in inches.	G. Weight in lbs. per foot.	P. Capacity in cwts.
0·63	0·13	3·54
0·78	0·20	5·51
0·90	0·27	7·28
1·02	0·34	9·25
1·14	0·43	11·61
1·29	0·56	14·96
1·42	0·66	17·72
1·53	0·78	20·86
1·81	1·09	29·13
2·04	1·39	37·20

Wire Ropes.

Taking the usual form of wire rope, viz., that in which the wires are twisted, in much the same way as hemp, into strands, and the strands again round a hemp core, with the respective angles of 8° to 15° for the strands and 10° to 25° for the rope, the same remarks apply to the advantages and losses as to hemp rope.

The strength of iron wire per square inch lies between 85,320 lbs. and 108,072 lbs., and is proportionately greater for thin and unheated wire than for wire which is thick and which has been subjected to heat. The most usual thickness of wire for pit ropes lies between 0·0354 inch and 0·1350 inch.

Having regard to the fact that, owing to the twist, the resistance to strain of a rope is lessened by the flexure to which it is subjected in passing over the drum and roller, six times the breaking weight must be adopted in determining the absolute capacity of bearing, P, and the safe load must not be more than 14,223 lbs. (6·349 tons) per square inch.

If δ be the diameter of the wire in inches, and n, the number of wires, P is obtained from the following equation:—

$$P = 14{,}223\, n \frac{\delta^2 \pi}{4} : 11{,}170 n\, \delta^2 \quad . \quad . \quad . \quad . \quad (3)$$

To express P in terms of the diameter, d, of the rope, the relation, $\frac{d}{\delta}$, must be ascertained; this is obviously not only dependent on the number, n, but also on the strength or diameter, δ, of the wire, and is therefore somewhat variable. The following table gives the necessary factors. The proportion of $\frac{d}{\delta}$ in the general form of rope, consisting of thirty-six wires, is from 9 to 10, *i.e.*, $\frac{d}{\delta} = 9 \cdot 5$. To obtain this value with $n = 36$, equation 3 becomes

$$P = 14{,}223 \times 3 \cdot 2\, d^2 \text{ approximately} \quad . \quad . \quad (4)$$

The weight, G, per lineal foot of wire rope in lbs. is nearly

$$\left.\begin{array}{ll} & G = 3 \cdot 268\, n\, \delta^2 \\ \text{or} & G = 1 \cdot 341\, d^2 \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

when δ and d are expressed in inches.

TABLE for USE of ROUND IRON WIRE ROPES.

Diameter in inches. d.	Thickness of Wire in inches. δ.	Number of Wires. n.	Weight per lineal foot in lbs.	Absolute Capacity of Bearing six times Breaking Weight in lbs.
0·27	0·035	24	0·14	440
0·31	0·035	36	0·21	660
0·39	0·035	42	0·25	770
0·43	0·047	36	0·32	926
0·51	0·047	42	0·38	1,100
0·59	0·059	36	0·49	1,540
0·63	0·059	42	0·56	1,830
0·71	0·075	36	0·70	2,530
0·78	0·075	42	0·84	2,710
0·87	0·075	49	0·91	3,150
0·90	0·098	36	1·12	4,040
0·98	0·098	42	1·40	4,630
	0·075	84	1·58	5,400
1·10	0·107	42	1·58	5,400
1·18	0·098	49	1·65	5,400
	0·123	36	1·68	5,952
	0·075	114	2·11	7,340
1·30	0·123	42	2·01	6,990
	0·138	36	2·11	7,340
	0·098	72	2·32	7,716
1·38	0·123	49	2·46	8,090
	0·138	42	2·62	8,550
	0·098	84	2·65	9,190
1·50	0·098	98	3·07	10,650
1·58	0·138	49	3·17	10,100
	0·098	114	3·59	12,570
	0·123	84	3·67	13,600
1·69	0·098	133	4·56	14,700
1·77	0·123	114	5·29	18,740
1·97	0·123	133	6·13	22,040
	0·138	114	6·75	23,520

IRON CHAINS.

Adopting the elliptical form and the strength, as given by the English Admiralty, viz., to that of round iron as 11 : 9, and about 56,890 lbs. per square inch, or with six times the breaking weight, 9,956 lbs. per square inch, with d = diameter of iron in inches, P = the capacity of bearing in lbs.

$$P = \frac{9956\, d^2 \pi}{4} \cdot \frac{9}{11} = 6397\, d^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The weight, G, per lineal foot in lbs. $= 10 \cdot 079\, d^2$ (7)

Comparing the weight of these three materials with equal power of resistance, and calling the diameter (in inches) of the hemp rope d_1, of the wire rope d_2, and of the chain iron d_3, there is obtained from the equations 1, 4, and 6

$$P = 0 \cdot 7\, d_1^2 = 3 \cdot 2\, d_2^2 = 7\, d_3^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The relative weights, G_1, G_2, and G_3, of the hemp, wire, and chain are according to the equations 2, 5, and 7, as

$$0 \cdot 3376\, d_1^2 : 1 \cdot 341\, d_2^2 : 10 \cdot 079\, d_3^2$$

or $$G_1 : G_2 : G_3 = d_1^2 : 4\, d_2^2 : 30\, d_3^2 \quad . \quad . \quad . \quad . \quad (9)$$

Comparing these weights with ropes or chains of equal power of resistance, that is, transferring the values d_2^2 and d_3^2, resulting from equation 8, into equation 9, viz.,

$$d_2^2 = 0 \cdot 22\, d_1^2 \text{ and } d_3^2 = 0 \cdot 1\, d_1^2,$$

there is obtained $G_1 : G_2 : G_3 = d_1^2 : 0 \cdot 88\, d_1^2 : 3\, d_1^2$,

or $$G_1 : G_2 : G_3 = 100 : 88 : 300.$$

Considering that the cost of

1 lb. of	hemp rope is about	7·2	pence.
1 „	wire rope „	4·0	„
1 „	chain „	3·6	„

the proportion between the cost of hemp rope, wire rope, and chain will be as

800 : 396 : 1,200, or nearly as 2 : 1 : 3.

The wire rope is therefore, under the same conditions of resistance, twice as cheap as hemp rope and three times as cheap as iron chains.

The Author gives, in addition, the following formula for calculating the size of drums, D = diameter:—

For hemp rope $D \gtreqless 8\, d$ (d diameter of rope).
Wire „ $D \gtreqless 1{,}100\, \delta$ (δ thickness of wires).
Chain $D \gtreqless 24\, d$ (d diameter of link of chain).

W. E. T.

The Performance of Compressed Air, applied to the Transmission of Mechanical Work. By Paul Piccard.

(Bulletin de la Société Vaudoise des Ingénieurs et des Architectes, 1876, p. 10.)

This is mainly a summary of the results to which known formulæ lead, and a statement as to the efficiency which may be expected from the use of compressed air.

Compressed air renders 100 per cent. of the work expended in compression, when it is worked reversely by expansion, supposing the conditions remain unaltered. But, in practice, the conditions vary greatly. When a gas is compressed, its temperature is raised; when it is expanded on a piston, the temperature falls. Thus, if atmospheric air at 32° Fahr. be compressed from its ordinary

pressure, adiabatically (that is, neither receiving nor parting with heat), or, reversely, if it be expanded adiabatically from higher to atmospheric pressure on a piston, the temperatures will rise and fall in the two cases, as is here exemplified for pressures of from 2 to 10 atmospheres, taken as the final pressures in compression, or the initial pressures in expansion:—

Atmospheres: Final in Compression, Initial in Expansion.	Final Temperatures by Compression. ° F.	Final Temperatures by Expansion. ° F.
2	141	− 58
4	275	− 131
6	367	− 168
8	439	− 190
10	498	− 207

With such large variations of temperature the adiabatic condition is destroyed. Much heat is unavoidably radiated and conducted. When compressed air is delivered into a reservoir, and passed through long pipes, the temperature falls to that of the surrounding atmosphere, and the volume is contracted, causing a material loss of power for work. The Author applies the ordinary formulæ for the relations of the pressure, volume, and temperature of air compressed and expanded, to three cases, for which he adopts the initial temperature 0° C., or 32° Fahr. He supposes that, in the 1st and 2nd cases, the pressure and temperature are raised adiabatically, and that the temperature relapses to the normal point 0° C., before the air is applied to work; and in the 3rd case, that the temperature is constant at 0° C. whilst the air undergoes compression.

1st case. Air compressed, cooled, and expanded within the same cylinder, without any reservoir. 2nd case. Air cooled in a reservoir. 3rd case. Air cooled during compression. The pressure to which the air is compressed is, in each case, 6 atmospheres; but the final volumes, taking the initial volume as 1, are—

	Fraction of Initial Volume.	During the Interval
1st case . .	0·2806, or 1-3·5	Pressure falls to 3·56 atmospheres.
2nd case . .	0·2806, or 1-3·5	Volume reduced to $\frac{1}{8}$ initial.
3rd case . .	0·1667, or 1-6	Pressure and volume stationary.

The final pressures, volumes, and temperatures are subjoined; and, to these are added the efficiency for each case, or the ratio of the useful work done to the work expended in producing the supply of compressed air:—

	Final Pressure. Atmospheres.	Final Volume. Total = 1.	Final Temperature. Initial = 0° C. ° C.	° F.	Efficiency. Compression = 1. Per cent.
1st case . .	1	0·69	− 84·2 or	− 119	36·4
2nd case . .	1	0·595	− 110·6 „	− 168	59·2
3rd case . .	1	0·595	− 110·6 „	− 168	78·0

Ordinary practical conditions oscillate between cases 2 and 3; and it is clear that, the more the air is cooled during the process

of compression, the less is the expenditure of work on compression, and the greater is the efficiency.

The less the degree of compression, the greater is the efficiency; because the less is the proportional loss from the intermediate reduction of temperature. For pressures of from 1 to 10 atmospheres, the following are the respective efficiencies in the 3rd case, and also when the air is not worked expansively, but is admitted for the whole of the stroke:—

Pressures.	Efficiency in the 3rd Case. Per cent.	Efficiency, without Expansion. Per cent.
1	100	100
2	90·6	72·1
4	82·4	54·1
6	78·0	46·0
8	75·2	42·1
10	72·9	39·1

In either condition, it is seen that the efficiency is reduced as the pressure is multiplied. Add, that the efficiency of the machines themselves is a factor; and, if it be taken at 70 per cent. for each case, the compounded efficiency is 49 per cent., or, say, a half. The above noted efficiencies are therefore to be halved, to show the ultimate efficiency of the combined air-compressor and motor. In general practice, it rarely exceeds 30 per cent.

D. K. C.

On the Calculation of Continuous Girders, when the Variation of the Moments of Inertia in the different Cross Sections is taken into Account. By M. KLEITZ.

(Annales des Ponts et Chaussées, vol. xi., p. 115.)

In calculating continuous beams by the usual method, the transverse section, or rather the moment of inertia of the beam, is assumed to be constant throughout the entire length. This hypothesis is far from agreeing with the reality, and consequently there is some uncertainty as to the importance of the error. Professor Rankine and M. Bresse have each given a formula, taking into account the variations of the cross section; but as they have recourse to integral calculus it is not well adapted for practical applications. The purpose of this Paper is to develop a formula more readily applicable, and afterwards to show its use by numerical examples.

When a continuous beam is to be calculated in the ordinary way, the bending moments at all the bearing points are first determined by a relation which exists between them at three consecutive bearings. The reactions, the shearing loads and bending moments for any other section of the beam, are then easily deduced from them. The Author proves that in the case of a

variable section there likewise exists a relation between the bending moments at three consecutive bearings.

Let the case be taken of one span of the continuous beam with a length, a, divided into a number, n, of elements of equal length, λ, throughout each of which the uniformly distributed load, p, and the moment of inertia, i, are constant. The number n being arbitrary, this is always possible. Of course p and i may, and will generally, be different for each element. For the next span, a', there will be another number, n', and other loads, p', and moments of inertia, i'. This understood, the Author applies to each of these elements the formulæ of resistance to bending, and after long eliminations, finally gets an equation containing only the bending moments at three consecutive bearings as unknown quantities. This equation is similar to the one ordinarily used, but its factors are more complicated.

If M, M', M'' = the bending moments at the three consecutive bearings,
a, a' = the lengths of the two consecutive spans,
p, p' = the uniformly distributed loads per unit of length in each respective span,
y, y', y'' = the ordinates of the three bearing points, supposing them not to be at the same level,
I = the moment of inertia, when supposed constant throughout, and
E = the modulus of elasticity,

then the formula ordinarily used can be expressed by:

$$a\,M + 2\,(a + a')\,M' + a'\,M'' = \frac{a^3}{4}p + \frac{a'^3}{4}p' + 6\,E\,I\left(\frac{y - y'}{a} + \frac{y'' - y'}{a'}\right) \quad . \quad . \quad . \quad . \quad (1)$$

When the three bearings are on the same level, the term $6\,E\,I \left(\frac{y - y'}{a} + \frac{y'' - y'}{a'}\right)$ disappears.

The Author's formula is:

$$\frac{G}{n^3} \cdot a \cdot M + \left(\frac{B}{n^3}a + \frac{B'}{n'^3}a'\right)M' + \frac{G'}{n'^3} \cdot a' \cdot M'' = \frac{H}{n^5} \cdot \frac{a^3}{4} + \frac{H'}{n'^5} \cdot \frac{a'^3}{4} + 6\,E\left(\frac{y - y'}{a} + \frac{y'' - y'}{a'}\right) \quad . \quad . \quad . \quad . \quad (2)$$

M, M', M''; a, a'; y, y', y'', and E have the same meaning as before.

G, B, H and G', B', H' are factors referring to each span respectively. They are each composed of series of n and n' terms, in which enter the varying loads p, p', and moments of inertia i, i'. The working out of these factors is, in general, long and troublesome, but can be greatly simplified for practical purposes: 1st, by

supposing the live load in each span to be represented by a uniformly distributed load, instead of single loads; and 2ndly, by assuming the moments of inertia to vary as the ratio of simple numbers.

The Author shows that both these hypotheses are admissible in practice with a sufficient degree of approximation.

The mode of applying the formula is simply this:—

In a first rough calculation the moment of inertia is supposed constant, and $n' = n$, choosing for n a suitable number, say 20. By equation (2) the bending moments at the bearings, and those at the other sections of the beam, are then determined. This enables an approximate division of the metal to be adopted, and consequently an approximate variation of the moments of inertia. Then equation (2) is applied for the second time, and the factors are again calculated, with due regard to the varying moments of inertia just determined. It will be noticed that the results of this second application are only approximate; but a third application would prove the corrections to be so small that it is unnecessary to have recourse to it.

The continuous beams which the Author considers in his numerical examples have all level bearings; their intermediate spans have a length a, and the two end ones a length $a \times \sqrt{\frac{2}{3}} = \cdot 8165\, a$. This assumption corresponds to the case of a continuous girder which, when loaded with a uniformly distributed load, deflects in the same manner as if it were fixed at the intermediate bearings; or, in other words, at these bearings the direction of the tangents to the curve of the centres of gravity of the sections is not altered by the deflection.

Before concluding, the Author compares the results of his calculations with those furnished by the usual method, and finds that the hypothesis of the constancy of the moment of inertia leads to values too low for the greatest positive bending moments, and too high for the greatest negative ones. In the particular kind of continuous girder just defined the error can amount in the first instance to 9 per cent., and in the second to 14 per cent.

A. O. B.

Bridge over the Dwina at Riga.

(Nouvelles Annales de la Construction, vol. xxi., p. 153.)

One of the largest bridges recently constructed, and presenting great difficulties in execution, is that over the Dwina at Riga, the capital of Russian Livonia, a town of 102,000 inhabitants.

The river, in its ordinary flow as rapid as the Rhine or Rhone, is liable to sudden floods, as well as to the passage of masses of ice during the breaking up of the cold weather. The bridges of the North of Russia cannot be built on iron cylinder piers, as these do not present sufficient lateral stability to resist the packing

of the ice against them, and the severe blows from large masses of floating ice.

The Riga bridge has a total length of 2,440 feet, and consists of eight spans of 272 feet 4 inches in the clear, or 283 feet 2 inches from centre to centre of the piers. There is an opening span of 65 feet 7 inches over the right bank of the river (on the town side) for the passage of vessels, and an equal length over the quay for the convenience of traffic. The piers are not at right angles to the line of the bridge—which crosses the river at a slight skew—but have their greatest length parallel to the direction of the current. The piers are 64 feet 3 inches in length, and 15 feet 9 inches in width at the foundations, diminishing to 9 feet 10 inches at the girder beds. At their up-stream ends they are carried out a distance of 13 feet 3 inches at the water-level to form ice-breakers, wedge-shaped in plan, and battering at an angle of about 40° from 4 feet above ordinary water-level to the ordinary ice-level. Taking the ordinary level of the water as datum, the lowest known water in the river corresponds to 3 feet 6 inches below it; the ordinary ice-level to 9 feet 2 inches above, and the level of extraordinary floods to 15 feet. The piers are of masonry, built in wrought-iron caissons and faced with granite from Stockholm and Karlskrona. In order to carry on the work uninterruptedly during the severe cold of winter, each pier was covered with a timber shed, consisting of double planking, with a thickness of 15 inches of moss interposed, and warmed by means of the exhaust steam from the engines. The caissons were 64 feet 3 inches in length, and 15 feet 9 inches in width, built of boiler plate $\frac{5}{16}$ inch thick, stiffened with vertical ribs at distances of 3 feet $5\frac{1}{4}$ inches from centre to centre, composed of a cover plate and two angle irons 3 inches by 3 inches by $\frac{3}{8}$ inch, and of horizontal angle irons of the same section, at a distance of 2 feet 7 inches apart.

The air-tight compartment, which extended over the whole area was 8 feet in height, and was covered by a boiler-plate floor of $\frac{5}{16}$-inch plate, carried by longitudinal and transverse girders 1 foot $9\frac{3}{4}$ inches deep. This floor was pierced by two circular boiler-plate wells, 3 feet $3\frac{1}{2}$ inches in diameter, provided with air-locks, for hoisting out the material excavated and for the passage of the workmen. The outer skin of the caisson was carried up to the level of the water, and within it the pier was built, leaving a space for the shafts. The operations of sinking were carried on in the air-tight chamber of the caisson, by compressed air supplied by pumps worked by engines on a raft moored immediately below the pier. When at the greatest depth, viz., $65\frac{1}{2}$ feet, the air-pressure was so severe for the workmen that only the strongest could withstand it. German workmen refused to go down, as they could not remain conscious for more than ten minutes, and only the most robust Russians could be induced to sustain their courage by a constant application of strong liquor. The main girders crossing the 272-feet 4-inch spans were 31 feet 6 inches in depth, consisting of a top and bottom boom, 3 feet $3\frac{1}{2}$ inches wide, united by

two systems of lattice bars 1 foot 11⅝ inches from centre to centre. The width of the bridge outside the main girders is 35 feet 9½ inches, or, inclusive of the footways on each side, 44 feet 1½ inch.

The first pile was driven, May 10, 1871. The staging for the first caisson was commenced, May 13. The sinking of the first caisson was commenced, July 20. The depth to which the caissons were sunk in the earth was 58 feet. The first locomotive crossed the bridge, October 15, 1872. The execution of the work, therefore, occupied one year, five months, five days.

	Tons.	Kilogrammes.
The total weight of the superstructure is .	4,931·696	5,011,887
The weight of the cast-iron girder beds is .	112·825	114,660
The weight of the hand-rails is	106·780	108,517
The weight of the caissons is	607·984	617,870
Total weight of iron employed in the bridge	5,759·285	5,852,934

To afford an idea of the size of this bridge, as compared with others of large dimensions, the following table of weights is given:—

	Tons.	Kilogrammes.
Total weight of bridge over Danube at Vienna	2,932·320	2,980,000
" " Fribourg Viaduct on iron cylinders.	2,980·339	3,028,800
" " Orival Viaduct.	1,326·432	1,348,000
" " Bridge over Rhone at Arles . .	1,869·600	1,900,000
" " Brest Swing Bridge . . .	1,220·000	1,250,000
" " Kehl Bridge over the Rhine.	2,446·049	2,493,952

Cost of the Riga Bridge.

	£.	Francs.
Ironwork in superstructure and caissons .	175,588	4,389,700
Cost of sinking caissons	32,800	820,000
Masonry of piers and abutments, including quays, foundations, &c.	88,000	2,200,000
Staging, temporary bridge, workshops, &c .	26,000	650,000
Platform and footways.	6,400	160,000
Painting and sundries	3,560	89,000
Total cost	332,348	8,308,700

A. T. A.

The Moerdijk Bridge over the Hollandsche Diep on the Antwerp and Rotterdam Railway.[1] By M. Baude.

(Bulletin de la Société d'Encouragement, 3rd series, vol. iii., p. 231, 1 pl.)

The Hollandsche Diep, an estuary formed by the confluence of the Rhine and the Maas, is about 2,840 yards wide, where the bridge for the Antwerp and Rotterdam railway crosses it near the village of Moerdijk. The bridge consists of a fixed portion of fourteen

[1] *Vide* Minutes of Proceedings, Inst. C.E., Vol. xlii., p. 213; and "Notice sur les Travaux Publics en Hollande," par M. Ph. Croizette Desnoyers, 4to, Paris, 1874, pp. 111-136.—Sec. Inst. C.E.

spans, each 328 feet from centre to centre of the piers, and of a swing bridge spanning two openings, and resting on a central pier, affording two passages for the navigation, each 52 feet 6 inches wide, which are dredged to a depth of 19 feet 6 inches below low water. The swing bridge is connected with the other portion by an embankment 233 feet long. The work also includes an embankment on each side of the bridge to the bank. The bed of the river is composed of silt and sand, and three of the piers had to be founded at a depth of from 65 to 85 feet below high-water mark. This was accomplished by sinking a large wrought-iron caisson on the site of each pier, and excavating and building up the pier inside, compressed air being employed. The rest of the piers were built upon piles, driven about 60 feet into the bed of the river, and cut off at the level of 23 feet below low-water mark. The foundation piles of each pier were encircled by sheet piling connected by walings, and the space inside was filled with concrete up to 7 feet 3 inches below low-water mark, the bed of concrete on which the piers were built being 16 feet thick. A mound of large rubble stones was deposited round the sheet piling, having a base of 30 feet, and resting upon a layer of interlaced fascine-work. The embankments, formed of sand, were deposited on a foundation layer of fascine-work, and the slopes were protected by fascines nearly up to low water. The main iron girders spanning the openings have a double row of struts and ties connecting the top and bottom flanges; the width of the roadway between the girders is 14 feet 9 inches. The girders across the fourteen openings are not continuous; they are each 342 feet 6 inches in length, 39 feet 4 inches high in the centre, and 19 feet 8 inches high at the extremities, the top flange being curved and the bottom straight; each pair of girders are braced together at the top, and the cross girders, 1 foot 8 inches in depth, which support the roadway, connect them at the bottom. The weight of the superstructure across each opening is 490 tons. The yard in which the girders were put together was intersected by canals leading to the Maas, and each girder after being lifted and conveyed to the river by barges and buoys, was raised on pontoons, so that at high water the bottom was level with the top of the piers, when it was floated into its place and deposited on the piers. The total length of the bridge and embankments is 1 mile 4 furlongs 203 yards, and the yost was £520,000. The iron superstructure cost £80 per lineal card, the price of the iron-work being £16 5*s.* per ton.

L. V. H.

On the Set of Bars of Wood, Iron, and Steel, after a Transverse Stress. By PROF. W. A. NORTON, Yale College.

(American Journal of Science and Arts, 3rd series, vol. xi., p. 284.)

This Paper contains a summary of the general conclusions drawn by the Author from his experiments, which were prosecuted in three series:—1. Sets from momentary strains. 2. Sets

from prolonged strains. 3. Duration of set, and variation of set with interval of time after the withdrawal of the stress. The bars in most of the experiments consisted, one of white pine, 3 inches square and 4 feet long; another of wrought iron, 1 inch deep, $\frac{1}{4}$ inch wide, and 4 feet long; and a third of steel, of the same dimensions as the iron bar.

The immediate set—that is, the residual deflection which obtains immediately after the transverse stress is withdrawn—varies nearly as the stress applied; until, beyond a certain limit, the set increases in a greater ratio. The immediate set is also augmented with the duration of the stress, up to a certain limit of time: with white pine the limit of time varied, with the strain, from ten minutes to one hour. The immediate set, after a prolonged strain, is from five to nine times as great as that which succeeds a momentary strain; it is also greater when the maximum stress is reached by successive stages than when the total stress is directly applied. When the same stress is repeated on the same bar, after a short interval of time, the set first obtained is not augmented, when the load applied is within a given amount. When the load is in excess of this amount the set is augmented by each repetition of the load.

There is no discernible limit of elasticity; a perceptible set is obtained, however small the load applied. But when it is less than about 0·0005 inch it vanishes in a few minutes. When it is greater than this proportion it decreases in a short interval of time, of from five to twenty minutes, according to the duration of the stress; and then usually increases during a longer interval, when in less than an hour the set is increased to an amount even greater than the set observed immediately after the stress is withdrawn. The set again eventually decreased. In some experiments the set was increased by reaction to about double the initial set.

D. K. C.

Remarks on the Strain to which Axles are subjected when Tested. By W. Liehmann.

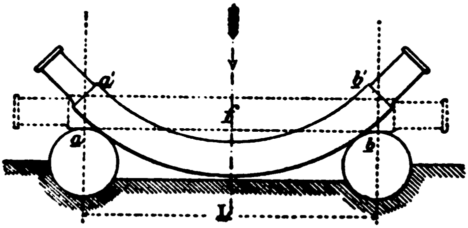
(Technische Blätter, vol. viii., p. 16.)

An axle when tested is laid on two firm supports and subjected to the blows of a weight falling from different heights, until, after having been repeatedly bent, straightened, and rebent, it is at last broken. The firmness, toughness, and power of resistance of the material are proportionate to the power required to break the axle and the extent to which the bending can be repeated. As a rule a given total of momenta is required before a rupture takes place; the individual momenta being the product of the falling weight G multiplied by the terminal velocity of it, falling from the height H, as

$$M = G v = G \sqrt{2 g H}.$$

It will be later shown that this is not a scientific formula.

If the weight G fall from the height H on to the axle supported at *a* and *b*, it will deflect it until its deflecting power is exhausted by the resistance of the material.



Although this expression is in a general sense correct, the following calculation is only applicable within the limits of elasticity, because the behaviour of the body after the limit of elasticity has been exceeded is not subject to any known laws. The effect of the monkey falling is A = G H. The bending effect is the resistance of the material during the entire operation of deflection; this resistance is, however, variable, and dependent on the relation between the static load P, midway between the two supports, and the ordinate of the curve of deflection *f*, as given in the formula

$$f = \frac{P\,L^3}{48.\epsilon.J} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

L is the distance between the supports, ϵ the modulus of elasticity, and J the linear momentum of inertia.

From equation (1) is derived

$$P = \frac{48.\epsilon.J}{L^3} f.$$

P is then proportional to the amount of flexion, *f*, within the limits of elasticity.

The differential of the bending effect is

$$P\,df = d\,A' = \frac{48.\epsilon.J}{L^3} f.df.$$

The integration gives

$$A' = \frac{24.\epsilon.J}{L^3} f^2.$$

The bending effect $A' = A$ is of course then

$$G H = \frac{24.\epsilon.J}{L^3} f^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

From equation (2) it will be seen that the mechanical momentum G H increases with the square of the deflection, and decreases with

the cube of the distance between the supports. Further, if $\mathfrak{S}$ represents the strains to which the outer fibres are subjected, then because, as is known,

$$PL = 4\mathfrak{S}.\frac{J}{h},$$

the relation is expressed, in connection with equation (1), in the following equation:—

$$f = \frac{\mathfrak{S}\,L^2}{12.\epsilon.h} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This value of f, expressed in the equation (2), gives

$$GH = \frac{\mathfrak{S}^2.JL}{6\,\epsilon\,h^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

which expresses the relation between $\mathfrak{S}$ and the mechanical momenta in $GH = A$, and proves that the latter increases with the square of $\mathfrak{S}$.

For the circular cross section of the axle when d represents the diameter, because

$$J = \frac{\pi}{64}.d^4 \text{ and } h = \frac{d}{2},$$

the equation (4) becomes

$$GH = A. = \frac{\pi}{96}.\frac{\mathfrak{S}^2\,d^2}{\epsilon}.L \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The equation (5) is used in finding the mechanical momenta up to the limit of elasticity.

The limit of elasticity must always be exceeded in trials, because if it be not, there is theoretically no reason for a permanent change of form: what applies to the first applies equally to the following blows; therefore the axle would, in spite of the number, however many, remain unaltered. The tension up to the limit of elasticity may, for cast-steel axles, be taken (according to Reuleaux) as 63·5 tons per square inch (10,000 kilogrammes per square centimètre). The diameter of axles in the centre being 5·118 inches, a general value for L is 59·05 inches. ϵ is represented by 12,698. If these values are adopted in equation (5) then $GH = 2{,}996$ foot-pounds. If $G = 881{\cdot}6$ lbs. it follows that $H = 40{\cdot}78$ inches.

$G = 881{\cdot}6$ is a mean value for actual trials, nevertheless H is always greater than 39·37 inches, and, as experience has shown, the limit of elasticity is exceeded, as proved by the permanent deflection.

If $\mathfrak{S}$ be determined from equation (5) then

$$\mathfrak{S} = \frac{5{\cdot}53}{d}\sqrt{\epsilon.\frac{A}{L}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and from equation (6) the important inference is obtained that $\mathfrak{S}$

increases with the $\sqrt{A}$ and decreases with the $\sqrt{L}$. The strain $\mathfrak{S}$ decreases by the increase of L, or, in other words, by enlarging the distance between the supports. As an example in illustration, the Austrian North-Western railway, when testing axles, require a distance between the supports of 62·2 inches, a weight of 881·6 lbs. and a fall at the first blow of 9·84 feet; whereas at the trials made at Messrs. Cockerill's works in Belgium, the weight is 1542·8 lbs., the fall 13·13 feet, and the distance between supports 36·22 inches.

At the Austrian N. W. Ry.	$A = 881 \cdot 6 \times 9 \cdot 84 = 8,675$ foot-lbs.
„ „ „	$L = 5 \cdot 19$ feet (62·2 inches).
According to Belgian experience	$A' = 1542 \cdot 8 \times 13 \cdot 13 = 20,256$ foot-lbs.
„ „ „	$L' = 3 \cdot 01$ feet (36·22 inches).

If $\mathfrak{S}$ and $\mathfrak{S}'$ be respectively the relative strains to which the material is subjected, the proportions are as follows:—

$$\mathfrak{S} : \mathfrak{S}' = \sqrt{\frac{A}{L}} : \sqrt{\frac{A'}{L'}};$$

or $$\mathfrak{S} : \mathfrak{S}' = \sqrt{\frac{8,675}{5 \cdot 19}} : \sqrt{\frac{20,256}{3 \cdot 01}};$$

or $$\mathfrak{S} : \mathfrak{S}' = 41 \cdot 5 : 83;$$

or $$\mathfrak{S} : \mathfrak{S}' = 1 : 2.$$

$\mathfrak{S}'$ then $= 2\,\mathfrak{S}$, *i.e.* the material is subjected to twice as severe a test in Belgium as on the Austrian North-Western railway. In the above analysis only the actual effective work g H of the weight is taken into consideration, not, however, the momenta spoken of in the beginning, viz.:—

$$G v = G \sqrt{2 g H}.$$

If $M = G H$ and $M', = G \sqrt{2 g} H$, then $M = M' \sqrt{\frac{H}{2g}}$, and M must be greater than M′, as long as $H < 2g$. A certain total of momenta ΣM will be obtained sooner than the added actual effective work which the weight produces, and this will increase in proportion as H decreases. Hence it follows that one and the same total momentum, $\Sigma G v$, arises in different methods, and requires a greater or less amount of work, $\Sigma G H$, according to the fall, H, on which it depends, and is in no way connected with producing the actual effect. The rule, therefore, to bring about a certain total momentum, $\Sigma G v$, in testing axles must be declared as unscientific. The total moment should rather be based on the total effect G H. This is not only the simplest, but also the most natural rule.

W. E. T.

On the Tensile Strength of Vegetable Parchment.
By A. LÜDICKE.

(Civilingenieur, vol. xxii., p. 155.)

The experiments described in this Paper were made with a view of furnishing additional information in regard to the so-called parchment paper, of which the knowledge has hitherto been imperfect and without numerical data. The material experimented upon was pure cotton paper, made by E. Dieterich, of Helfenberg, near Dresden.

The production of parchment paper is effected by running the web of unsized paper, as it leaves the machine, through a mixture of sulphuric acid and water, after which it is carefully washed to remove the acid. At the works in question the acid bath contained 9 to 9½ parts of English sulphuric acid of 58° to 60° Beaumé to 1 of water, the weight of the mixture being about five times that of the paper treated. The temperature of the bath is kept down to 10° C., and the time of immersion is three seconds. These factors are, however, liable to variation according to differences in the raw materials operated upon.

The change effected by the acid consists in a superficial conversion of the cellulose into a substance analogous to starch (the so-called hydrocellulose of Girard), which forms a cement closely uniting the unaltered fibres. This is accompanied by a contraction of area of from 5 to 10 per cent., and a loss of not less than 10 per cent. in weight.

The results obtained by the Author from the examination of three samples of the same paper, both before and after treatment with acid, are contained in the following table. The amount of moisture and ash were determined by Mr. Meugel, a student in the Polytechnic laboratory at Dresden.

No.	Description.	Thickness.	Specific Gravity.	Tensile Strength per Millimètre in Kilogrammes.	Hygroscopic Water. Per cent.	Ash. Per cent.
		Millimètre.				
1	Plain paper . . .	0·234	0·617	1·415	6·785	0·633
	Parchment do. . .	0·152	0·964	6·436	8·778	0·496
2	Plain do. . . .	0·178	0·543	1·483	7·071	0·645
	Parchment do. . .	0·113	0·937	5·111	8·483	0·458
3	Plain do. . . .	0·134	0·624	1·503	6·978	0·678
	Parchment do. . .	0·088	0·927	5·777	9·160	0·559

The contraction in thickness of the paper by the treatment in acid varies from 34 to 37 per cent., while the increase in specific gravity is from 32 to 42 per cent.

The increase in strength in the different samples was—

In No. 1	. . . . . .	4·55 times that of the natural paper.
„ 2	. . . . . .	3·44 „ „
„ 3	. . . . . .	3·84 „ „

When parchment paper is softened in water for a short time, its strength is found to be diminished to about 0·6 as a minimum of that obtained when in an air-dried condition.

The loss of ash is due to the action of the acid on the mineral matter in the fibre producing soluble salts, which are removed in the subsequent washing.

The lower the temperature at which the operation is performed the stronger is the parchment paper obtained. It is, however, difficult to regulate the temperature, owing to the heat developed in the acid bath. For this reason the Author did not think it necessary to make experiments upon this point, as the results could not be of any practical value for the carrying out of the process, which depends upon many contingencies that can only be controlled by the experienced eye of the manufacturer.

H. B.

Actinometric Measures made at the Summit of Mont Blanc. By M. J. Violle.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 896.)

Direct experiment has shown that the rate of cooling in vacuo of either of two thermometers on the summit of Mont Blanc is equal to $0\cdot22\,\theta$ when the excess θ is small. The observed excess in vacuo should then be at the summit $\Theta_1 = \frac{6\cdot552}{0\cdot22} = 29^\circ\cdot78$, and at Bossons $\Theta_2 = \frac{5\cdot540}{0\cdot22} = 25^\circ\cdot18$. In a previous communication the Author has indicated another method for determining the temperature in vacuo for a thermometer submitted to the influence of solar radiation. This method consists in working with another thermometer of different dimensions, and comparing the temperatures given at the same instant by the two instruments. It may be applied to calculate Θ_2. One of the thermometers indicated $12^\circ\cdot75$, the other $10^\circ\cdot8$. The thermometers had for the respective radii of their reservoirs 4·4 millimètres and 3 millimètres. Admitting loss by air, the value in vacuo is furnished by either of the two equal expressions—

$$12\cdot75 + \frac{m}{4\cdot4}\,12\cdot75^{1\cdot233} = 10\cdot8 + \frac{m}{3}\,10\cdot8^{1\cdot233}$$

whence obtaining the value of m, that of Θ_2 is immediately found

to be = 25°·06. Admitting the exactness of the law of Dulong and Petit for all temperatures, the effective temperature of the sun may be taken at about 1,500°, and the mean probable temperature of its surface between 2,000° and 3,000°.

P. H.

Description and Results of Hydraulic Experiments with large Apertures. By T. G. Ellis.

(Transactions of the American Society of Civil Engineers, vol. v., p. 19.)

These experiments were conducted in a lock 100 feet long, 16 feet wide, 20 feet lift, and of ordinary construction. The experimental orifices were attached to an opening cut in a bulkhead, thrown across the lock 50 feet above the lower gates. At the latter a dam was fixed, forming a receiving basin and measuring weir, whose crest was an iron plate, 5½ inches wide, and ½ inch thick, accurately planed, and projecting 1 inch above the wooden sill, to which it was attached.

Along the inside of this dam there was a perforated copper pipe, communicating, by a flexible tube, with a bucket, arranged with a pulley and weight. Above this bucket, a hook gauge was firmly attached to the masonry, in such a manner that, with the point of the hook at the surface of the water, the scale would range from zero at the crest of the weir to above the greatest depths used in the experiments. It was found impossible to keep a perfectly fixed head on the discharging orifice, and thus the experiments were made in series, while the water in the flume was rising or falling at a nearly uniform rate. The velocity of approach at the measuring weir was allowed for, when this quantity affected the result by more than 0·001 cubic foot per minute. Leakage was also carefully measured, and the discharge corrected accordingly. A diagram was made, from which the leakage at any height could be scaled to 0·001 cubic foot per minute.

A correction was allowed for the time occupied in raising or lowering the level of the weir basin to the proper height so as to make the measured discharge equal to that flowing from the aperture at any given instant of time. When computing the quantities flowing over the weir, the approximate discharge was calculated from Francis's weir formula. The corrections for velocity of approach, leakage, and variation in level of weir basin were then made, giving as a final result the true discharge from an aperture under a mean given head.

If g = force of gravity in this case, 32·16107,
h = head on centre of aperture,
A = area of aperture in feet,
D = actual discharge,

the theoretical discharge is

$$60\sqrt{2gh} \times A \text{ cubic feet per minute,}$$

and the coefficient

$$\frac{D}{60\sqrt{2g}\sqrt{h} \times A}.$$

Where Francis's formula was used, very few depths were under 0·55 foot on the crest of the weir, and none under 0·28 foot. The Author assimilated his weir as much as possible to Mr. Francis's to secure similar results. A comparison was made between Francis's formula and the results of experiments by Poncelet and Lesbros, and other observers, taken with smaller heads, to ascertain their differences; and for obtaining the actual discharge of the weir at heads of from 0·05 to 0·09 foot, a comparison was made between long and short weirs with the same volume of discharge, the shorter weir running clear from the sharp inside edge of the crest, and the longer weir below 0·09 foot in depth of water, so that the weir followed the top surface of the crest. The discharge was in all cases greater with the lower heads, commencing at 0·25 foot in depth on the weir, and increasing to 6 per cent. more than the amount given by Francis's formula when the weir followed the top surface of the crest. All the quantities of leakage were corrected in this manner, where the weir height was less than 0·25 foot. Above that height Francis's formula was assumed to give the correct discharge.

The following table gives the general features of the results:—

Aperture.			No. of Experiments.	True Discharge. Cubic feet per minute.	Mean Head on Centre of Aperture.	Co-efficient.
Horizontal.	Vertical.	Area.				
Feet.	Feet.	Square feet.				
2·00	1·99975	3·9995	20	1683·88	2·0660	0·60871
			16	2194·30	3·5408	0·60591
2·00	1·00	2·00	26	773·64	1·8096	0·59757
			10	1957·42	11·3140	0·60466
2·00	0·50	1·00	9	351·08	1·4239	0·61141
			12	1190·55	16·9652	0·60067
1·0000833	1·0000833	1·00017	10	439·22	2·3234	0·59871
			9	1250·01	18·4540	0·60459
Same aperture with curved approach			10	798·40	3·0416	0·95118
			11	1939·04	18·2263	0·94370
2 feet dia. round.		3·14159	13	1182·44	1·7677	0·58829
			8	2887·76	9·6381	0·61530
1·0007 foot dia. round.		0·78650	10	232·86	1·1473	0·57442
			10	953·61	17·7150	0·59865
0·5 foot dia. round.		0·19635	12	83·19	2·1516	0·60025
			5	234·09	17·2650	0·59626

J. C. I.

Fireless Locomotives.

(Revue Industrielle, vol. vii., p. 258.)

A short abstract is given of an experimental investigation by M. Piarron de Mondésir, from which the Author takes, as a basis for calculation, the following deductions:—1. A production of steam equal to one-ninth of the weight of the heated water. 2. An effective work of 5,260 foot-lbs. performed per lb. of the initial quantity of water and steam, between the limits of 367° and 277° Fahr. The Author adds a third deduction, adopted from M. Spée, that the co-efficient of traction on a level is one-fiftieth of the gross weight. Let p = the weight of the heated water; P = the gross weight to be drawn; l = the equivalent length of the line, reduced for a level and straight line. Then

$$\frac{p + P}{50} \times l = 1{,}600\, p;$$

whence $$p = \frac{P\, l}{80{,}000 - l};\ \text{and}\ l = \frac{80{,}000\, p}{P + p}.$$

The co-efficient of tractional resistance, $\frac{1}{50}$, seems rather too large, though it is deduced from experiment; but the Author employs it, in order to afford ample margin for contingent resistances. Some engineers adopt a co-efficient of $\frac{1}{100}$ for a straight line in good order, and $\frac{1}{1000}$, or $\frac{1}{91}$, for curves.

M. L. Francq's fireless locomotive for tramways, recently constructed, and capable of travelling from 9 to 12 miles, presents a few novel features. The reservoir contains a body of water heated by steam from a boiler to a temperature of 392° Fahr. The steam from the reservoir is admitted to an intermediate chamber, where it is maintained at a fixed pressure, the degree of which is adjusted by means of a throttle-valve. There is a pair of vertical cylinders which work an intermediate crank-shaft, from which the four wheels are driven by outside coupling-rods. It is in contemplation to apply three cylinders to work as compound cylinders. The exhaust steam is delivered into surface-condensers. By a system of double frame, the passage over curves is facilitated. The four wheels are 26 inches in diameter, on axles 55 inches apart, controlled by a break having eight blocks, which are applied to the wheels successively. The stopping is thus effected promptly and without shock.

D. K. C.

Tramways in Belgium. By M. Raillard.

(Annales des Ponts et Chaussées, vol. xi., p. 539.)

This notice contains the results of the Author's inquiries into the system of tramways in Belgium with reference to a line projected for the town of Lille, under his direction. Concessions for tramways in Belgium are usually granted by the local administrations.

There are, altogether, 38½ miles of tramway, all of recent construction. The oldest line is that of the Bois de la Cambre, at Brussels, 4⅓ miles in length, which was completed in 1869; all the other lines have been constructed since 1871. Their lengths, gauge of way, weight of rails, and other particulars are given in the annexed table:—

Tramways in Belgium at December 31, 1874.

Total length 38·62 miles.

—	Brussels.	Anvers.	Liége.	Gand.
Nature of traffic . . .	Passenger	Passenger	Pass. & Goods	Passenger
Length of double line, miles	19·29	0·30	..	0·16
„ single „ „	3·73	5·86	4·78	4·50
Total length of lines „	23·02	6·16	4·78	4·66
	Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.
Gauge of way	4 8½	4 5½	4 8½	4 8½
Interspace for double lines . . . . feet	3·28 to 2·62	3·28	4·92 to 5·74	3·44
Minimum width of street for tramway „	24·6	23·0	19·7	16·4
			Pass. Goods.	
Minimum radius . „	46·0	82·0	82·0 246·0	49·2
Weight of rails, lbs. per yd.	24½ to 52	30·0	56·0	24·0

At Liége only has it been contemplated to work railway goods-traffic over the tramways. The sharp curves which have been sanctioned offer serious resistance to the passage of railway stock. At Liége, on curves of from 246 to 250 feet, or less than 4 chains radius, the power of 12 horses has been found necessary to draw a locomotive of 30 or 40 tons, or more than three times as much as is required for drawing the same engine on a straight line.

In Brussels, the tramways are worked by four distinct companies, each employing a special form of rail; the prevalent section is flat, about 4 inches wide, and grooved for the flanges of the wheels, laid on and screwed to longitudinal sleepers, which rest on and are fixed to transverse sleepers. No breakage of rails has taken place, and the system of permanent way is found generally sufficient for stability. The single doubtful element is the mode of fastening the rail to the longitudinal by wooden screws, which are apt to work loose.

The cars on the various lines are from 18 feet to 22 feet in length, and from 6 feet 10 inches to 7 feet 2½ inches in width. The prevailing width is 6 feet 10½ inches (2·10 mètres). The number of seats for passengers varies from twenty-four to sixty; but experience points to the conclusion that, for regular service, cars for thirty passengers are the most suitable.

The Belgian Street Railway Company have made trials of steam-traction, apparently with success.[1] The locomotive is fitted with a boiler on Perkins's system, worked with a pressure of from 30 to 40 atmospheres; the steam is generated with a natural draught, and, when exhausted, it is condensed in a multitubular air-surface condenser, whence it is returned to the boiler.

The report enters minutely into a discussion of the proportions of grooves in the rails, and the adaptations required on curves, to meet the requirements of merchandise traffic.

D. K. C.

On the Use of Santorin Earth in the construction of Hydraulic Works on the Sea Coast. By Joseph Prucha.

(Stummer's Ingenieur, vol. iv., pp. 248 & 265.)

For hydraulic works on the Mediterranean coast Santorin earth recommends itself through facility of excavation and lading and economical transport by sea. No special care is required to guard it against the effects of weather; and when mixed with proper proportions of stone and lime, absolutely water-tight works may be constructed.

It occurs as a natural product in the group of islands of that name forming part of the Grecian Archipelago, which has been the scene of various volcanic eruptions, during the last of which, in May 1867, two new islets came into existence. The Island of Santorin proper is principally composed of basaltic and trachitic rocks, rising in abrupt peaks, at many places covered to a depth of 25 to 50 feet with ashes and lava. These ashes, constituting the Santorin earth, may be easily obtained and shipped direct from the shore, and are so abundant as to afford practically an inexhaustible supply. They occur in the form of a coarse, sharp-grained powder of a light ash-grey colour, mixed in varying proportions with small fragments of pumice-stone and obsidian, also occasional pieces of lava, porphyry, and trachite, the two latter substances being interspersed with feldspar, quartz, and crystals of augite.

The mean of several analyses (none of which varied to a notable

---

[1] It is reported in the "Journal of the Society of Arts," August 11, 1876, that within the last few weeks a steam-drawn tram-car, the invention of M. Duroy, has been in daily use on the Bois de la Cambre line.—Sec. Inst. C.E.

U 2

extent) of Santorin earth collected from various situations is as follows:—

			Portion soluble in hydrochloric acid.
Silicious earth	67·35	Silicious earth	5·87
Clay	13·25	Lime	3·04
Potash	4·32	Oxide of iron	4·06
Soda	4·02	Water	1·43
Lime	3·19		
Oxides of iron and titanium	4·91		
Oxide of manganese	1·53		
Water	1·43		
Total	100·00		

In comparison with the above are given analyses of trass and puzzolana:—

	Trass. In hydrochloric acid. Soluble.	Trass. In hydrochloric acid. Insoluble.	Trass. Total.	Puzzolana.
Silicious earth	11·50	37·44	48·94	44·5
Clay	17·70	1·25	18·95	15·0
Potash	0·08	0·29	0·37	1·4
Soda	2·44	1·12	3·56	4·1
Lime	3·16	2·25	5·41	8·8
Oxides of iron and titanium	11·77	0·57	12·34	12·0
Oxide of manganese	2·15	0·27	2·42	4·7
Water	7·65	..	7·65	9·2

From the foregoing tables it will be seen that there is a much greater amount of silica in the Santorin earth than in either trass or puzzolana, also that a considerable quantity of silicious acid must be combined with it to account for its comparative insolubility in hydrochloric acid.

The chemical constituents of Santorin earth correspond with those of most of the glass-forming substances, and would be highly suitable for producing glass were it not for the presence of iron imparting an objectionable green tint.

When washed and allowed to subside, this earth may be separated into three portions. The first, amounting to about 5 per cent. of the whole mass, consists of pumice-stone, which possesses the least specific gravity, and remains on the surface; the second comprises a light, grey-coloured powder, intermixed with the heavier particles of pumice-stone; whilst the third and lowest layer is a sharp-grained sand, principally composed of obsidian. Of these the mid-layer may be regarded as the active setting agent, and the remainder as a good quartz sand, which requires a longer time to combine with the lime.

A piece of Santorin mortar two years old when fractured should exhibit a surface of a dark, steel-grey colour, the smaller particles of pumice-stone being thoroughly indurated, the grains of sand undistinguishable, and the whole mass perfectly homogeneous.

After exposure to the atmosphere the fractured surface should assume a lighter tint.

	Per cubic yard.
	lbs.
The weight of this earth when thoroughly dry and unpressed averages	1,324
" " when fresh, and consequently somewhat damp	1,390
" " when subjected to pressure may be increased by nearly one-third, viz.	1,793

The Santorin earth possesses many advantages in point of economy for the construction of heavy works where it is not necessary that the béton should immediately consolidate; it also requires less care and preparation in mixing than other cements and hydraulic limes, as no special apparatus is necessary, and the moulds can be removed after a few days; the labour of preparation is small, and the work may be continued without fear of interruption from bad weather. It is, however, important when mixing the mortar that the proper proportions of Santorin earth and lime should be employed, and that for subaqueous works there should be an addition of moderate-sized ballast.

The result of the experiments on the amount of contraction to which this earth is subject proved that each cubic foot contracts to the extent of 0·57 of its bulk, so that if this deficiency be made up with lime, there will be a proportion of about 7 parts of the former to 3 parts of the latter. This great amount of contraction need not be entirely compensated for by the addition of lime, as only a portion of it can be of actual service as a setting agent, the rest being merely used to make up the deficiency in volume, which is perhaps better attained by adding, say, one-sixth of fine sea sand, which fills all interstices and prevents percolation.

For the Mole works at Fiume, in the year 1850, the following proportions were adopted with very satisfactory results, viz.:—

Cubic contents of ingredients before mixing.	Cubic contents of ingredients after mixing and setting.
	Cubic feet.
6 cubic feet of Santorin earth $\times (1 - 0{\cdot}43) = 0{\cdot}57$.	3·42
2 " slaked lime.	2·00
1 " sea sand	0·58
9	6·00

Where the mortar is intended to be subjected to the influence of water while fresh a still larger proportion of lime should be employed, and indeed, under any circumstances, an excess of lime cannot act detrimentally. Where practicable, however, the mortar should not be submerged before attaining a certain degree of cohesion in the moulding boxes, which is generally reached in from twenty-four to thirty-six hours, and if then placed under water, it will form in from six to eight days a strongly cohesive mass, an advantage which, for extensive harbour works, must be regarded as of great importance. For walls of moderate height,

and, say, 6 to 9 feet in breadth, the moulding frames may be removed in from two to four weeks without fear of injury from waves. In more substantial works, such as at Pola,[1] where the walls were of an average breadth of 24 feet, and of considerable height, the moulding frames should remain undisturbed for five to six months, as the setting of the interior of such large masses proceeds at a comparatively slow rate.

In mixing the béton sharp broken stone should be used, if possible, in preference to river ballast (unbroken), and the Santorin earth should be thoroughly washed before use, to insure its being free from earthy particles.

The composition of the béton adopted in the construction of the following works is next given:—

	Slip and Dry Docks at the Austrian Lloyd's Arsenal, Trieste.	Larger Dry Dock at the Austrian Lloyd's Arsenal, Trieste.	Imperial Dry Dock at Pola.
	Per cubic yard.	Per cubic yard.	Per cubic yard.
Broken stone. . . .	19·00 cubic feet.	18·14 cubic feet.	19·00 cubic feet.
Santorin earth . . .	17·50 "	17·22 "	17·50 "
Slaked lime	5·83 "	6·45 "	6·31 "
Sand	2·90 "	2·86 "	1·65 "

The proportion adopted for the works at Pola surpassed the most sanguine expectations, and is recommended as the best standard.

The béton may be mixed either by hand or by machinery, though the latter is preferable. When first submerged, the action of water is liable to remove a portion of the surface lime, leaving the upper part of the block covered with a thin layer of pumice-stone. Before the next tier of blocks is placed in position, these particles should be removed by agitating the water, or otherwise, as, if this is not attended to, the works are likely to be leaky.

Where subaqueous works, after having been commenced, are for a time delayed, silicate of lime is likely to accumulate (especially in still water) on the upper surface of the béton. This should be carefully removed before continuing the works.

A table giving the strength of Santorin mortar of various ages then follows:—

Age of Mortar.	Resistance to Crushing, per square inch.	
	lbs. (English).	lbs. (Vienna).
4 months	275	223
9 "	467	378
1 year	448	363
1½ "	445	360
1¾ "	473	383
1⅚ "	488	393
2¼ years	673	542
4 "	833	675
13 "	1,404	1,137

[1] An account of the Pola dock and station will be found in the Minutes of Proceedings Inst. C.E., vol. xxxii., pp. 65–93.

In comparison with the above are next given the crushing resistances of

	lbs. (English).	lbs. (Vienna).
Brick	617 to 988	500 to 800
Sandstone	1,480 „ 13,580	1,200 „ 11,000
Limestone	1,853 „ 13,580	1,500 „ 11,000

Santorin earth was first utilised in the year 1843 by the Government Chief Engineer, R. von Körber, for both subaqueous and inland works. At Venice also several canal walls have been constructed of this material.

D. G.

The Bay of Saint-Jean-de-Luz. By M. Bouquet de la Grye.

(Annales des Ponts et Chaussées, 5th Series, vol. xi., p. 395, 2 pl.)

The Bay of Saint-Jean-de-Luz is open to the north and north-west; it is terminated on the west by the promontory of Socoa, and on the east by Barbe Point. The town of Saint-Jean-de-Luz is situated in the south-eastern corner of the bay. In the centre of the entrance to the bay stands the Artha Rock, and the deepest passage is between this rock and Socoa. The river Nivelle flows into the bay at the western extremity of the town, and the river Oncin near Socoa. The rise of the water at spring tides is 15 feet 7 inches. The greatest seas come from the west and west-north-west, the waves outside the bay attaining a height of about 23 feet, and a length of from 400 to 600 feet; but fortunately in the autumn and winter the wind blows generally from the south, otherwise the town would have long ago been washed away. The bay was formerly very dangerous for vessels, on account of its exposure to the sea, the variety of the currents, and the surf on the Criquas off Socoa. The river Nivelle afforded the only safe anchorage before any works were commenced, and the advantages of this shelter have been diminished by the formation of a bar at its mouth. The waves in a storm break on the Artha Rock, and render the eastern outlet impassable, sweeping round the bay from Barbe Point past the town, their force being concentrated on the shore west of the town, near the mouth of the Nivelle. There is also an outward undercurrent, caused by the returning water flowing down the steep beach, which increases the encroachments on the shore.

A breakwater was formed at Socoa about the commencement of the seventeenth century. Early in the following century the Nivelle was embanked to provide a greater scour at its mouth, the breakwater at Socoa, which had been partially destroyed, was extended, and a jetty formed to protect a portion of the town. Later in the century a sea-wall was built to secure the town from the encroachments of the sea, and two parallel jetties were constructed at the mouth of the Nivelle to improve the entrance.

The sea washed away the wall in 1782, and another sea-wall was built the same year farther inland. In 1783 it was proposed to form an inclosed harbour of the whole of the bay, and breakwaters were commenced from Socoa and Barbe Points; but in 1787, when the breakwaters had reached the length of 588 and 486 feet respectively, the work was discontinued for want of funds, and the sea gradually demolished a great portion of these structures. The sea-wall of 1782 was in its turn washed away. About 1823 a new wall was built, which is still in existence, and was extended in 1873. In 1864 the project of converting the bay into a harbour was revived, and the Socoa Breakwater had been extended in 1873 to a length of 1,280 feet, and a breakwater 820 feet long has been commenced across the Artha Rock, which will leave a passage to the west of 770 feet, and only a small opening on the east side to allow the currents to run unimpeded, and thus avoid silting up. The action of the sea in the bay has made the mouth of the Nivelle travel westward, and forced the mouth of the Oncin towards Socoa. Opposite the town the average annual encroachment on the shore of low-water mark has been 3 feet 9 inches between the years 1787 and 1864, and between 1864 and 1873 the low-water mark has encroached on the shore in some places and receded in others, giving on the average a retrogression of 7 inches annually. The average annual encroachment of the 3-mètre line was 4 feet 6 inches between 1787 and 1864, and 5½ inches between 1864 and 1873, and of the 6-mètre line 6 feet 7½ inches and 12 feet 3½ inches respectively. The construction of the breakwater at Socoa tends to turn the greatest force of the current in the bay towards the east; but whilst the shelter is being much improved, the area of the harbour suitable for anchorage is being diminished. This shoaling, however, which occurs chiefly on the west side of the bay, appears to be caused in great measure by material washed from the shore; and if the works stop the encroachment on the east side of the bay to the extent anticipated, the only sources of silt will be from the Nivelle, and whatever may enter the bay, travelling slowly along the coast from the mouth of the Bidassoa, giving an annual deposit amounting to only 38,000 cubic yards. The works have hitherto caused quite as much improvement in the state of the bay as was anticipated, and when they are completed it seems probable that the inroads of the sea will be gradually stopped, or so much localised as to be easily guarded against, whilst the shelter already afforded is eagerly sought.

L. V. H.

The Slips for building Men-of-War at Kiel. By H. Franzius.

(Zeitschrift des Architekten- und Ingenieur-Vereins, Hannover, vol. xxii., p. 49.)

The ordinary slips for shipbuilding and launching simply consist of a strong inclined beam, founded on piles, carried down 6·5 feet under water-level. Staple balks guide the vessel in

launching; but when she has reached the end of the slip there is a moment when one end of her keel dips into the water while the other still rests on the beam, whereby she is frequently exposed to great strain and dangerous deflection. Such slips, in fact, are no longer practicable for modern men-of-war, whose weight is so great, sometimes exceeding 5,000 tons, and whose breadth so considerable, that it is necessary to fix them in a cradle, resting on two parallel slips, half the breadth of the vessel apart, and carried so far under water, that the vessel may be gradually brought into deep water without a jerk and a strain on her beam.

The three slips built within the last few years at Kiel consist of two parts, the building-slip proper, which is shut off from the harbour by a pontoon, and is kept dry, and the so-called fore-slip (Vorhellung), which is entirely under water, and only serves for supporting the vessel when it is being launched. The building-slip is an inclined plane of solid masonry, with a slope of 1 in 16; the length is 431 feet; the breadth of the part above the water-level is 37 feet, and of the part below the water-level 78 feet. At intervals of 6 feet there are notches for supporting balks about 3 feet high, to allow men sufficient room to work under the bottom. When the ship is ready for launching, scaffolding is erected to carry the greased beams upon which the cradle slides, after which the ship is raised by wedges until entirely supported by the cradle. The end of this part of the slip is horizontal, so that the pontoon which closes it need not be of great draught. The latter is 20 feet high, with a breadth of 7 feet on deck, 15·7 feet at the sides, and a length of 66 feet. It is fitted with two hand pumps for pumping the rain-water out of the dock, two pumps for emptying the hulk, two valves in the keel, 1 foot in diameter, for letting water into the dock, so that it can be filled in eighty minutes, and valves for admitting water into the hulk as ballast.

The fore-slip has also a solid masonry foundation, with a slope of 1 in 14, a length of 103 feet, and a breadth of 36 feet, and is carried down to 18 feet below mean water-level. As the greased beams cannot be laid upon the masonry, and do not always have the same slope, a scaffolding, with a slope of 1 in 14 at the bottom and greased beams at the top, with a slope of 1 in 16, 1 in 14, or 1 in 12, is floated in position on the occasion of a launch, and is kept in place by chains and ballast iron.

The geological formation of the creek was a mixture of clay and bog-earth, bedded on sand. As the weight was calculated to be about $1\frac{1}{2}$ ton per square foot, and the upper strata were not deemed able to bear this, it was decided to drive sheet piles into the underlying sand. The ground was first excavated by steam dredgers, and then two steam pile-drivers were employed. The piles were cut off with a segmental saw, 13 to 16 feet under water-level. Where the building-slip joins the fore-slip, a coffer-dam was erected, the water from the building-slip was pumped out, and two layers of concrete, each 3 feet thick, were put on the piling. The mortar consisted of 1 part of cement and 1·4 part of sand;

the concrete had 43·6 parts of mortar to 100 parts of rubble. It was decided to make the concrete so fat because of the large quantities of mud, which gave rise to the apprehension that a greater part of the cement might be lost. The concrete was poured in boxes of about 1 cubic yard capacity each, six of which were arranged on a floating platform of the breadth of the dock, and the laying was commenced from the deepest part upwards. As soon as the first layer was put down for some yards, the mud was removed by hand dredgers and mud pumps, the surface cleaned with brooms, and the second layer deposited immediately afterwards. One hundred men were able to lay about 160 cubic yards in a day of ten hours.

The bottom being well dried, it was covered with several courses of brickwork, and the side walls were begun. After a few days, when they had been raised to 7 feet, a narrow crack was observed in the centre of the slope, and about 50 feet long, through which a slight spring of water appeared. By putting on additional layers of brickwork, the water was made to disappear. As the concrete, however, was deemed too rich, the following proportions were subsequently adopted:—Fore-slip No. I., 52·7 parts of mortar (1 part of cement, 2·5 parts of sand), 100 parts of rubble. Building-slip No. II., 61·7 parts of mortar (1 part of cement and 2 parts of sand), 100 parts of rubble. Fore-slip No. II., 50 parts of mortar (1 part of sand, 1 of trass, and 1 of lime), 100 parts of rubble. Building-slip No. III., 50 parts of mortar (1 part of sand, 0·94 of trass, 1 of lime), 100 parts of rubble. Fore-slip No. III., 50 parts of mortar (1 part of sand, 1 of trass, 1 of lime), 100 parts of rubble.

The trass concrete used in the last three cases was mixed by the same drums, and also put down in two layers. It proved of excellent consistency, the mud between the layers decreased, and the mixing process could be carried on more rapidly, 170 cubic yards being the average daily quantity, and 275 cubic yards the maximum, produced by the same machines, which could not mix more than 150 cubic yards of cement concrete. The cement decided upon, after many trials, by the Harbour Committee, was required not to settle until after it had been mixed for thirty minutes with water of 63° Fahr., and the temperature was required not to rise more than 3° to 4°. The powder had to run through a sieve with 2,580 meshes to the square inch, without leaving anything behind. The tensile strength was fixed at 2·6 lbs. per square inch after eight days, and at 3·1 lbs. per square inch after thirty days. The cost of the first building-slip, including pontoon, was £24,200; of the fore-slip, including the floating scaffolding for launching, £3,400. Building-slips II. and III., including pontoons, cost £76,500. The cost of the two fore-slips, including scaffolding, was £65,000. The wood was obtained from Pomerania or Poland. The granite was obtained from Sweden at a cost of 4s. per cubic foot. Elaborate tables of cost of material accompany the article.

L. E.

Construction of Breakwaters in the Harbour of Barcelona.
By D. M. Garran.

(Revista de Obras Publicas, vol. xxiv., p. 50, 2 pl.)

The object of this Paper is simply to describe the mode of construction of these works, as practically carried out, without touching upon any theoretical considerations as to the method employed.

There are two breakwaters. That to the east of the harbour is in water with a maximum depth of 66 feet; that to the west in water averaging 33 to 36 feet. They are entirely formed of large blocks of natural rock, described as first-class when measuring from 2 to 4 cubic yards, and as second-class when measuring from 1 to 2 cubic yards. The half of the breakwater facing the sea is formed, up to the water-line, of first-class blocks, the half which faces the shore of second-class blocks, and above the water-level the larger blocks are almost entirely employed. The inclination or slope of the exterior face is $1\frac{1}{2}$ to 1; that of the inner wall, up to the water-level, is 1 to 1; above that level the inner wall is nearly vertical; the width at the top, which is 20 feet above the sea-level, is 60 feet, and it is constructed with a sunken roadway on the harbour side, the roadway being 17 feet in width, and about 10 feet below the summit of the breakwater.

The western breakwater starts from one of the quarries on the shore, and the blocks were carried upon a tramway, gradually advanced as the work proceeded, to the site where the stone was to be used.

For the eastern breakwater the blocks had to be conveyed in large barges holding from 120 to 180 tons of stone. These barges were generally about 80 feet long and 30 feet wide, made of oak, and the lighter parts of native pine, with six lines of tramway on their deck, of the same width as the tramways used in the stone quarries, viz., of 2-feet gauge, so that the trucks ran from the quarry on to the barges. At the extremity of four of these lines of tramway revolving platforms were placed, on to which the loaded trucks were successively run, when the platforms swung round, tipped to an angle of 45°, and the blocks of stone slid into the sea. After the stone had been in this manner discharged, the trucks returned empty along the other two lines.

Each barge was manned by ten men, of whom three were sailors. Each barge held from thirty to forty trucks, and on reaching its destination it was anchored, and discharged in from fifteen to twenty minutes. From five to six barges were discharged per diem, and the maximum quantity of stone placed by them in one month was 17,111 cubic yards, so that the breakwaters have required many years to construct.

The blocks were placed in continuous layers, varying from 3 to 5 yards in thickness, each of the whole width corresponding to that portion of the breakwater, by which means all undue heaping

of the stones in unsafe positions was avoided; whilst care was also taken to give the proper inclination to the face of the walls, and to allow the settlement due to their great weight to progress evenly and with regularity.

Part of the eastern breakwater is on a curve, which increased the difficulty of confining the blocks to the precise lines of construction; but by marking the direction carefully with long flagstaffs and buoys in advance of the work, and taking frequent soundings, the barges could always be anchored in the proper spot. It was found advisable that the outer boundary line should always be first laid and allowed to settle, after which it was easy to fill in the central portions of the mass, which settled much less. As soon as the stones reached to within view of the surface of the water, two, and afterwards three, steam cranes were used to place each block more precisely in position. On the side facing the harbour the blocks have been cut and squared and the joints filled with mortar, but the upper surface of the breakwaters is still unfinished.

The Author is of opinion that wherever the blocks are exposed to rough weather a greater inclination than 1½ to 1 would be advisable, for sometimes even the largest blocks near the surface have been lifted by the sea and thrown over the top of the breakwater. The extent of the breakwaters is not given in this Paper, but it is considerable.

O. C. D. R.

Levees as a System for Reclaiming Lowlands.

By G. W. R. Bayley.

(Transactions of the American Society of Civil Engineers, vol. v., p. 115.)

After giving a general sketch of the systems of levees in Europe from the most ancient times, the irrigation system of India and China, and the results of the levee system applied to the reclamation of the *tula* land in the valley of the Sacramento and San Joaquin rivers in California, the Author goes fully into the history of levees on the Mississippi. Their construction began at New Orleans in about the year 1720, and it progressed gradually downwards for about 70 miles, and upwards nearly 1,000 miles, during one hundred and fifty years. If the effect of closing outlets and confining all the water to the river is to raise the flood line, there should be evidence of increased elevation in the lower river. Every original outlet, except the Bayou Lafourche, the high-water capacity of which is less than 12,000 cubic feet per second, has been closed below Red river; the Bayou Plaquemine, discharging about 35,000 cubic feet per second, was the last closed in 1865, and the outlet capacity of the crevasses which have occurred within the last ten years, because of neglect of or defective levees, is far smaller than formerly. There is evidence that the normal flood

line of the Mississippi, from Red river to the head of the passes, is not higher now than in 1727, before the commencement of levees. This is proved by the streets of New Orleans, which in that year were at least 3 feet below the river flood line, and are so now; and also by the lowest river-level in front of New Orleans being 0·8 foot below mean tide, and 0·2 foot below mean tide in the Gulf, at the mouth of the river, or 14·8 feet below the 1862 flood mark, which has never since been exceeded. The extreme range of 15 feet observed at New Orleans in 1735, at the beginning of the levee system, slightly exceeded the extreme range of the 1862 mark.

Artificial reservoirs are inapplicable to the Mississippi river, and the natural swamp reservoirs are worse than useless for reducing the height of the river floods. The swamp basins between Cape Girardeau and the mouth of the Red river retain the water from the first rise, until discharging it from their outlet channels below, and thereby adding to the floods, which are thus prolonged and increased. A notable example of such an effect occurred in 1874. The largest of these swamp reservoir basins extends from the Arkansas river to the mouth of the Red river, the latter being its outlet channel. In 1874 many large crevasses were open in upper Louisiana and Lower Arkansas, and this immense basin, traversed by the Bayou Macon, Texas river, and other drainage outlets, was gradually filled to its utmost capacity. In addition, heavy rains caused a great flood in the Oauchita valley. About the 1st of April, 1874, this reservoir basin commenced discharging itself into the Mississippi through the mouth of the Red river, and over the Mississippi banks for more than 20 miles above the Red river. The river rose steadily, thenceforward, 50 inches above the point it had reached previously, or to a height of about 13 inches above the mark in 1862, which was the highest before recorded at Red River Landing. During the same period the river rose at Vicksburg but 9 inches, when it was 6 feet below its previous flood height, showing that the extraordinary height of the river, from Red river to Baton Rouge, above the highest preceding flood known, was due to a discharge out of the swamp reservoir basin.

Generally there is a succession of freshets from the great tributaries, and if the river were secured by continuous levees, each rise or swell would pass off by itself; none would overtake the one preceding it. In this, as well as in other respects, a perfect levee system would tend to lessen the danger of inundations; the river channel would be accommodated to its necessities, and the danger or liability reduced to its minimum.

'Cut-offs' precipitate the whole river upon a lower level below the bend cut-off, and for a time create a gorge. The velocity of the current, both above and below the cut-off, in consequence of the increased slope due to the shortening of the river, becomes much greater than before; while the caving of the river banks, because of the change in the direction and force of the current,

is accelerated. Farther below, the increase of current is diminis… and made to conform more nearly to the normal quantity. … tendency is to increase the length of the river again by excav… and lengthening the bends, and thus to reduce the surface … to what it was before the cut-off was made. Time is requi… to accomplish this, and during the process new levees must be built, farther back, on lower ground around the bends, and therefore higher, larger, and more expensive. The alluvial lands bordering upon the Mississippi slope rapidly from the river bank, a fall of 15 feet within 1 mile back being not uncommon above New Orleans. Every levee must be made longer and stronger, because higher, opposite a caving bend, the ground at each location being lower.

When the Mississippi banks were first secured by levees below Red river, embankments of from 4 to 5 feet in height only, with a crown of 4 feet and slopes of 2 to 1, were found sufficient around the bends, where now levees 15 feet, and even 20 feet high in some places, with 10 feet crown and slopes of 3 to 1, are needed. The new 15-feet levees contain nearly twelve times the quantity of earth that was required for the old levee. Every 'cut-off,' therefore, adds to the cost of levee maintenance, and increases the danger of inundations. Only two bends have been cut off below, and one opposite the mouth of the Red river, the extra distance round them averaging 20 miles, and the high-water fall across their necks being more than 4 feet. Therefore these three cut-offs shortened the river more than 60 miles, and added about 12 feet to the surface slope.

The average width of the Mississippi diminishes very much from the mouth of the Ohio to the passes, while the depth of the channel increases. The average width of the river from the Ohio to Red river is about 4,275 feet at high water, and 3,230 feet at low water; while the average width below the Red river is about 2,700 feet at high water, and 2,500 feet at low water. Opposite and below New Orleans the high-water depth of the river in places exceeds 180 feet, and it is generally more than 100 feet deep in mid-channel, at low water. Above the Red river the Mississippi, in ascending, decreases in depth between Memphis and the Ohio; at low water there is sometimes too little water for steamboats.

A recent comparison of cross sections of the river opposite Jackson and St. Anne Streets, New Orleans, by Prof. Forshey, taken in 1850 and 1872, shows an enlargement of the cross section in the one case of 54,000, and in the other of 56,000 square feet. The depth also had been increased from 150 to 165 feet in mid-channel on one section, and about 13 feet on the other. Another section opposite the lower city district, at Louisa Street, also showed a large increase of section. Opposite Baton Rouge, and in other places, the river is slightly widening, as well as deepening; and the levees have of necessity been reconstructed farther back on both sides, because of caving banks opposite each other, in straight reaches of the river.

The evil effect of outlets in contracting the channel is then illustrated. It is shown that where the river current is checked, more especially when the river is falling, a portion of the earthy matter held in suspension is dropped; the proportion of sediment deposited depending on the loss of current velocity. As the river falls, the bars help to direct the current against the banks in the bends, and much of the earthy material excavated in each caving bend is deposited on the next bar, particularly the coarser gravel or sand. A large outlet therefore reduces the mean velocity and increases the deposit.

During the flood of 1874, at the top of the rise, a crevasse, caused by a musk-rat burrow, occurred in the Bonnet Carré levee, 40 miles above New Orleans, on the 11th of April. It became 1,370 feet wide, with a channel in it 550 feet wide, 50 feet deep at high water, and extending ¼ mile to the back of the levee, where the land was 15 feet below the river flood line. On the 15th of July, when the river had fallen 15 feet, the water ceased to run through the crevasse channel. On the 20th, 21st, and 22nd of Sept., when the river was nearly at its lowest stage, 20 feet below high water, the Author measured and carefully sounded two river sections above this crevasse, and two below it, taking transit angles to each sounding, with the following results:—

Soundings.	Distance from Crevasse.	Width at Low Water.	Maximum Depth.	Mean Depth.	Sectional Area.	Width at High Water.
		Feet.	Feet.	Feet.	Square feet.	Feet.
1	1¾ mile above	2,886	110	64	184,653	3,120
2	1¾ „	3,014	79	54	164,167	3,210
Average	..	2,950	..	59	174,410	..
3	750 feet below	2,406	62	40	96,640	3,300
4	1,500 „	2,452	64	42·3	106,150	3,430
Average	..	2,429	..	41·65	101,395	..

It is not contended that the whole of the contraction of the channel below was due to the crevasse of 1874, but the following reasons are given for the belief that much of it was:—The river bed, where the upper sections were taken, consisted of firm blue clay, into which a sounding lead of 11 lbs. sunk from 1 to 2 inches only, all the way across; while the depths were tolerably uniform, all indicating a channel of full natural dimensions free from deposit. The bottom, where both the lower sections were taken, was a soft oozy mud, or silt, into which the sounding lead sank from 1 to 2 feet, except near the left bank, where the current was strongest, on the bend side of the river, where the bottom was also firm clay and free from deposits. Opposite the lower section the sandbar, on the right bank, had encroached upon the channel so much that

the low-water width had been reduced more than 500 feet, and a new sandy ridge, evidently a deposit made during the preceding high water, from 12 to 15 feet high at its lower end, had been formed above the low-water line and over the old bar, in a direction parallel with the thread of the current from the river above into the outlet. Extensive deposits of sand had been made on the right bank below, several feet high above low water, and extending several hundred feet out from the shore; these were known to be new.

Nowhere else can there be a more striking example of the evil effects of outlets than on the Red river; for the lakes above and below Threveport owe their origin to the great elevations of the bed and banks of the main river opposite them, caused by rafts and lateral outlets. The only remedy is the gradual and systematic reversal of the process, the building of levees, the cutting off the flow of water into the lakes, by the closure of outlets from below upwards, and the drainage of the lakes at their mouths by deep canals.

The Bayou Lafourche, the only original channel of the Mississippi left open below the Red river, is another example of the evil effects of outlets, and of constructing levees from the head of the stream downwards. Its levees do not extend to the Gulf, and outlets and crevasses are the rule yearly on the Lower Lafourche. These cause deposits in and contraction of the lower portion of the channel, and the raising of the opposite banks by deposits thereon. The result is the backing up of the water above, and the elevation of the flood line. Where levees of 2 or 3 feet formerly sufficed 50 or 60 miles below the head of the bayou, embankments of 10 feet in height, or more, are now required, while their height at the head of the bayou remains the same as at first; yet each year, before the main river reaches its full height, a break in the Lower Lafourche levees must occur, or the water must flow over them. The only remedy is the contraction of the bayou at its head and an extension of the levees to the mouth of the bayou, with a dredging-out of the lower contracted channel, if this bayou is to be left open. It would be better to close it altogether, and substitute a slackwater, or locked canal navigation, for outlets have ruined it, and are no benefit to the Mississippi river.

J. D. L.

On Cutting off a Bend of the Lower Rhine.

By W. H. HUBRECHT.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1875–76, p. 270.)

The course of the river Rhine through the alluvial soil of Holland is well known to be circuitous and liable to constant change. During the last four centuries ten bends of the principal channel or its branches have been corrected, by cut-offs

varying in length from 1,230 to 2,060 yards, the bends being in more than one case several miles long, and the effects upon the water-level and depth of the bed have been carefully watched and recorded. The operations here described were recommended by Wiebeking, in his book on "Wasserbaukunst," as far back as 1799, he being of opinion that the cutting off of the "Serpentine" below Wijk by Duerstede (about 12 miles south-west of Utrecht) would increase the velocity of the current, prevent the formation of ice barriers, and contribute to the scouring of the river bed. In the reports of several commissions appointed to inquire into the rectification of the river, the importance of this cut-off was dwelt upon, especially as likely to prevent the formation of ice barriers, which threatened not only the embankments or dykes, but the ancient walls of the city of Wijk. At ordinary seasons, the depth of the river was not considerable, being during the summer in many places not more than 3·28 feet; but during the winter of 1837–38 one of these barriers caused the water to rise to within 4 inches of the top of the dam, 12 feet above mean water-level.

Complaints were frequently made of the increase of groynes, or "kribben," which impeded the flow, and caused the banks to be continually shifting. The maps accompanying the article show that the river at this point describes a series of bends, resembling two letters S placed above each other; but the maps of 1789, 1838, and 1870, prove that these bends differed to the extent of several hundred yards during these three periods, and had so encroached upon the low banks in the last year as to cover a house which stood some distance off at the first period. Much of this was said to be due to the work of the engineers in France and Germany, who by various cut-offs had shortened the river 90 to 120 miles, in consequence of which, although the height of the stream was not permanently increased in summer, the floods came down more rapidly, rose to greater heights, and carried larger quantities of sand with them, which were deposited at the angles and corners of this Serpentine.

A commission of engineers proposed in 1864 that the tongue known as the Redfoot should be cut off by a canal, 88 feet broad at the bottom, sloping by 1 in 1 to 107 feet, and with a depth of 5·2 feet below mean river-level. The breadth of the river at mean water is from 500 to 890 feet, and the mean depth 15 feet, and it was expected that scouring would bring the dimensions of the cut-off equal to those of the river in six years. It was found, however, that scouring had by no means answered that purpose in all the cut-offs in Germany, the report on the Pannerden canal showing that, after thirty-eight years, its breadth was only 450 feet; while the cut-off below Spires, near Angelhof, had since 1826 only increased in breadth from 98 feet to 177 feet, and could not be expected to be opened for traffic for many years.

In 1866 and 1867, the necessary grant having been obtained from the Chamber, the ground on both sides of the proposed cutting which was not Crown property was bought, and soundings

taken above and below. In 1868 a length of 575 feet was cut on the down-stream side, embankments were thrown up, and two groynes run into the river. The section of the cutting finally fixed upon was 88 feet broad at the bottom, 5·2 feet below mean river-level, sloping by 1 in 1 to a breadth of 98·4 feet. The cutting was commenced on the down-stream side, because the depth of water at that point was less, and because at high water there was less danger of the cutting being filled with sand. It was, however, deemed necessary to dig or dredge until the sand was reached, for it had been found in other cut-offs that the process of scouring, both in depth and breadth, was much resisted by the clay. It was therefore resolved to let the depth depend upon the depth of the underlying sand, and to increase the breadth to 295 feet, or $\frac{2}{5}$ of the total breadth. A dam of 65·6 feet was left between the cutting and the river.

At the same time the river in front of the town of Wijk was examined, and it was found that, in consequence of the widening of the stream at that point, a bar of sand had formed in the centre, which impeded navigation and rendered the ferry below the town useless at low water. To correct this, a series of groynes, thirty in number, were constructed on both banks during 1869, 1870, and 1871, at an aggregate cost of £6,500, whereby the current of the river was confined to a definite channel. In some cases the heads of two groynes were joined by a dam; the entire length of the connection was about 2,700 yards; and the soundings taken in 1870 showed a least depth of 3·28 feet, and a greatest depth of 24·3 feet between the two sides of the ferry.

During 1871, the dam which still closed the cutting on the up-stream side had been gradually decreased to 10 feet at the crown. In the latter part of December ice began to settle in the bend. On the 28th, at the gauge close to the dam, the water stood at 15 feet above Amsterdam Peil; at the gauge near the town, past the bend, it stood at 11·2 feet 8 inches above A.P.; a difference of more than 3 feet, which was mainly due to the action of the ice barrier. During the night the water increased to 16·4 above A.P. at the one, and to 11·3 feet at the other. In consequence of the pressure of water, the sand under the clay of the dam seems to have been set in motion, for the clay began to fall away on the cutting-side in large masses. Not long afterwards the water made a breach of about 5 feet, which soon increased to 32 feet, and subsequently to 200 feet. The water rushed in with great violence, and at first the movement of sand seems to have been so considerable that the water was not able to carry it all off. This occasioned temporary shoals, and caused the current in some places to flow back with great rapidity.

On the 29th of December every obstruction had been removed and the course of the river shortened by 1,722 yards. On entering the cutting the water was of a clear green colour, but immediately afterwards yellow streaks became visible, and in the middle of its length it had changed to a deep sand colour. The

respective heights of the river on that day were 14·3 feet above A.P. above the cutting and 12·5 feet above A.P. below. On one bank 65 feet, on the other 130 feet, of the dam still remained, the depth of water in the breach being 10·5 feet. On the 30th the cutting became full of drift ice, and did not again become clear till the middle of January 1872, when the first six ships sailed through. The difference between the two gauges was then only 0·328 foot, the mean height being 12·8 feet above A.P. It was found, however, that the estimated breadth of 295 feet was too great to procure a current of sufficient strength for scouring. Shallows were formed, and seams of clay, resisting the action of the water, acted as submerged groynes, and caused undercurrents. The clay seams were therefore dredged by hand, and a dam 8·2 feet broad at the crown was thrown up for 328 yards across the down-stream mouth of the bend in the direction of the axis of the cutting, so as to lessen the current in the bend.

In January 1873 the bend was closed on the up-stream side by a dam of fascines and clay, the details of which may be found in a Paper "On the Use of Fascines in the Public Works of Holland."[1] The foundation of the dam, or "Zinkstuk," is 2·6 feet high and 82 feet broad, composed of fascine mattrasses loaded with stones. On this rises a fascine dam 48 feet broad at the base, 12·5 feet high, with a slope of 1 in 1, and a crown of 10 feet broad. On the down-stream side, the dam was afterwards strengthened with clay, sand, and stones for a further breadth of 82 feet at the base, the slopes being 4 in 1 and 6 in 1. It was commenced in the second week of January 1873, interrupted by high water from January 29 to February 3, and finally closed on February 23rd. Until March 28th the dam was under water, and when it was again examined it was found that, by the action of the water, large quantities of sand had been deposited in the fascine work and behind the dam. Within one day of the final closing the river at Cologne began to rise, and within five days, the depth in the cutting began to assume a regular character. At almost every point there was an increase of from 3 to 4 feet in depth, which in another month increased to 6 and 10 feet.

The total cost of the work was £38,135, of which £10,500 was paid for purchase of land. The quantity of earth removed by digging and dredging was 543,200 cubic yards, of which 140,000 cubic yards were under water. It is calculated that, after the opening of the cutting, three times the latter quantity was removed by scour, without causing any obstruction. The down-stream opening of the bend is closed halfway by a beam, but will not at present be permanently shut.

J. D. L.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xli., p. 158.

The Flood of the Seine of 17th March, 1876. By M. Belgrand.[1]

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 659.)

During the present century only two floods of the Seine have risen higher than the flood of the 17th of March, 1876, namely, one on the 3rd of January, 1802, which rose to 24 feet 5 inches on the gauge of the bridge of Tournelle, and another on the 2nd of March, 1807, which rose to 22 feet, whilst the flood under consideration reached 21 feet 4 inches. A flood in 1740 rose to 25 feet 11½ inches, and the discharge of the river amounted then to 464,600 gallons per second, whereas the smallest discharge of the river is 8,810 gallons per second. On the 13th of March, 1876, it was announced that the Seine, which had then reached 19 feet 4 inches on the gauge of the bridge of Austerlitz, would rise to 21 feet 4 inches on the 16th; and the next day it was stated that on the 17th the river would rise as high as 21 feet 11·7 inches on the gauge. These predictions were fulfilled within 0·4 inch. The floods of the Yonne, Marne, Aisne, and Oisne, tributaries of the Seine, have been similarly predicted; and by an application of the same principles the floods of some of the other great rivers of France, similar in character to the Seine, as, for instance, the Saône, might be announced beforehand.

L. V. H.

On the Irrigation in the Department of Bouches-du-Rhone. By J. A. Barral.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1311.)

The Author, having been appointed by the Minister of Agriculture, member and reporter of a commission on the best means of irrigation in the South of France, had occasion to make many observations and experiments. The irrigation works of the Bouches-du-Rhone extend over more than 86,500 acres, of which 63,000 are watered by the Durance, 13,000 by the Rhone, and 7,200 by the Huveaune, the Arc, the Touloubre, and other secondary streams. The waters of the Durance are conveyed, in the three departments, of Aix, Arles, and Marseille, by canals, some of which date from the sixteenth century, while others are scarcely completed. They all deliver water for agriculture from the 1st of April to the 30th of September, in quantities estimated at 0·7 pint per acre per second (1 litre per hectare). There was no irrigation during the winter until M. Faucon demonstrated the efficacy of submerging vines during autumn and winter to destroy the phylloxera. From that time many hundreds of acres of old and new vines are submerged during thirty or forty days between the beginning of October and the end of January. No other vines

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv., p. 263.

except those submerged now exist in the arrondissement of Arles, and these furnished last year a splendid yield.

The mode of distribution varies with the construction of the canals, but 2·1 feet is the total given for each acre, through twelve, twenty-three, twenty-nine, and, in some cases, forty-three channels of equal depths along the canals, those depths varying from 5·91 inches to 2·67 inches, 2·12 inches, and 1·5 inch. During three hours, for instance, about 7 gallons (per acre?) are given per second, forty-three times during the season, by which the soil is exposed to alternate periods of moisture and dryness. Each channelful of water drives the gases contained in the pores of the soil downward, and, when the water has sunk in, new air enters. The principle enunciated by M. Boussingault is here verified, for the fertilising action of irrigation is not carried on exclusively either by the nitrogenised substances (ammonia, nitric acid, or organic matter) dissolved in the water, nor by the mud held in suspension, for in neither of them is there found sufficient nitrogen, phosphorus, or potash, to explain the full harvests systematically yielded by all the lands irrigated in the department. The grass and lucerne fields give 63 cwt. to 95 cwt. of dried hay per acre containing 11 to 19 per cent. of water, whereas in other districts 30 to 32 cwt. per acre are considered excellent.

Analyses of hay from these districts show it to contain more nutritive qualities than that taken from fields which have been irrigated with much larger quantities of water, but more in winter and spring than in summer, and with fewer interruptions. The land irrigated in the department of Bouches-du-Rhone, after having been cleared, contains sufficient nourishment for sheep during winter. Large quantities of farm-sewage and guano are mixed with the water. For corn there were in 1875 only three irrigations in April and the first weeks in May, at the rate of 2·6 gallons per acre during six hours, the irrigated fields yielding in consequence 4·4 bushels per acre more than the non-irrigated fields. Olive trees are watered twice a year, in June and in August, with 13 gallons per second during two hours and a quarter. At night the temperature of the water exceeded that of the atmosphere.

J. D. L.

The Irrigation Works of Alicante, in Spain. By M. Aymard.

(Annales du Génie Civil, 2nd series, vol. iv., pp. 638 and 688.)

That part of the valley of the river Monegre called the "Orchard" begins about 5 miles from the city of Alicante, and forms a pleasing exception to the general aridity of the surrounding soil. The main cause of the superior fertility of this valley is the irrigation, carried on either by draw-wells or by pools and reservoirs for the collection of spring and rain water. The wells

are sunk till subterranean springs are reached, when horizontal galleries for collection are driven in various directions. The pools or reservoirs are excavated in the ground, and lined with solid masonry throughout. Among the most notable is that of "Garcia," built at the end of the last century, and entirely supplied by rain-water. It is 407 feet long, 131 feet wide, and 13 feet deep, and capable of containing 700,000 cubic feet of water. To diminish loss by evaporation, it is divided into two compartments connected by a sluice.

The so-called "Orchard" (Huerta) covers about 9,150 acres, and is devoted to the cultivation of vines, olives, fruit, and other market produce, which could only be reared by irrigation, as there is no rain at the most needful period. The largest reservoir used for the purpose is that of Tibi, near the village of that name, about 16 miles north of Alicante. A dam of limestone rock was built across the gorge, 29·5 feet long at the bottom, and 190 feet at the summit, the height being 134 feet in front and 140 feet in the rear, while the breadth at the summit is 65·6 feet, and at the base 110·6 feet. The capacity is estimated at 130,650,000 cubic feet, which is sufficient for two waterings of the vines and cereals per annum. The reservoir is fed by twenty-two streams, calculated to supply about 44 gallons per second. During the wet season these become torrents, and carry down enormous masses of rock; they are, however, so broken and reduced in their course, that the deposit against the face of the dam consists of the finest mud and sand. Every four years, when the accumulation reaches 40 to 50 feet, the water is drawn off, and the deposit cleared away, to effect which special wells and galleries have been constructed in the masonry of the dam.

At 2 feet from the face, in the body of the masonry, and following the pitch of the wall, a shaft 2·7 feet square runs from the summit to the base, having, at intervals of 1·4 foot, fifty-one pairs of loopholes about 8·7 inches square. This shaft ends in a gallery at the base, 5·6 feet high and 2 feet wide, running parallel for a certain distance with the face of the dam, until it reaches the rocky bank of the river, through which it is tunnelled in the direction of and towards the stream. The discharge is regulated by a sluice-gate, placed in a chamber cut in the rock in rear of the dam.

The gallery made through the dam for clearing the mud and deposit, which is 6 feet by 8·8 feet, widens to 13 feet by 19 feet at its mouth, where it is closed by a door, formed of pieces of pine 1 foot square, placed vertically side by side, caulked and run into masonry grooves at the top and bottom. Behind this is another door of similar construction, with the exception that the pine squares are placed horizontally, supported by three tightly-wedged vertical posts backed by props. When the time for cleaning arrives, the following method is adopted, although, when great care is not taken, it is attended with much danger. The time generally chosen is the spring, when the supply of water

in the reservoir is abundant, and the current comparatively powerful. The deposit, although consisting of fine mud, attains great consistency, so that 10 to 13 feet of water are required in the reservoir before commencing operations. Workmen remove the props, and loosen the doors carefully, when, if the mud is in motion, sufficient time is allowed the workmen to escape by the gallery. When the mud is too solid to move, a balk of timber carrying a pulley is laid on the top of the dam, and is projected beyond the face perpendicular to the door of the gallery. A long mining-bar, 58 feet long, 2¼ inches square, and weighing 1,100 lbs., attached to a rope worked by a windlass over the pulley, is then drilled into the mud until the pressure from the superincumbent water exceeds that of the mass, when a break-up takes place, and the mud and water burst with great noise through the gallery. The expense of each such operation does not exceed £10 10*s*.

About 8 miles lower down the river Monegre there are two other dams, named Muchamiel and San Juan. The former is 151 feet wide, 64 feet broad at the base, and 9 feet high; and from it the stream is diverted into a canal (Acequia Major) 6 miles in length, from which twenty-two secondary channels and numerous smaller ones are spread over the "Orchard." The dam of San Juan is constructed lower down the stream, to intercept the water which passes by and in floods over the Muchamiel dam. A canal joins the Acequia Major, and cuts across many of the secondary canals, which are thereby supplied if the water at the Muchamiel dam should become low.

In consequence of the cultivation of the upper lands, the amount of water in the reservoirs has of late years greatly decreased, to remedy which the authorities adopted the plan proposed by M. Llobet for intercepting the water ordinarily lost by filtration through the bed of the river. In 1862 a gallery 906 yards long, 4 feet wide, and of different depths, was built under the bed of the river, partly of brickwork and arching of an inexpensive yet solid construction, and partly tunnelled in the rock. When the gallery had been carried on for 29 yards from the dam there was an increase of about 5,300 gallons per hour, and when it had reached 60 yards that quantity had been doubled. It was expected that the entire gallery would largely increase the intake, but such has not proved to be the case. It has therefore been decided to cut another gallery in the gypsum banks farther up stream. The total cost of the work is estimated at from £24,000 to £30,000.

W. C. S.

Irrigation in the Provinces of Murcia and Albacete, Spain.

By F. de Botella.

(Supplement to the Revista de Obras Publicas, vol. xxiii., 1 pl.)

From a report to the Spanish Government it appears that these two provinces have a united area of about 10,570 square

miles, the western portion of which consists of mountainous forest lands, rising to a height of nearly 8,000 feet above the sea. The northern part of Albacete belongs to the former kingdom of New Castile, and is on high table-land; to the east lie the maritime provinces of Valencia and Alicante, and the Mediterranean itself forms the south-eastern boundary of the province of Murcia. On the elevated plains of Albacete the average temperature throughout the year is only 40° Fahr., but in the low lands of the province of Murcia this average is as high as 68° Fahr., which is that of a subtropical climate. The productions of the soil vary accordingly from rye and barley, the chestnut and pine, in the upper portions of the province of Albacete, to lemons and oranges, tomatoes, melons, dates, sugar and cotton in the subtropical regions about Murcia, Orihuela, and Carthagena.

The rainfall in the low-lying lands, however, is limited, and the inhabitants are greatly dependent on artificial irrigation. Without water, the parched lands will bear only insignificant crops; with it, the soil becomes marvellously productive; yet the proportion of the cultivated land which is irrigated to that which is not is only as 1 to 36 in the province of Albacete, and as 1 to 13 in the province of Murcia; and the total extent of irrigated land in the two provinces does not exceed 165,000 acres.

The principal sources from which water for irrigation is derived in the province of Murcia are the rivers Segura, with its several affluents, and the Guadalantin. For a distance of more than 50 miles above Murcia both banks of the Segura are irrigated by numerous canals, into which the brown, muddy water is driven by stone dams thrown at an acute angle across the river. Throughout the greater part of this distance, at Cieza, Avaran, Blanca, Ojós, Villanueva, Archena, and Ricote, as well as in the opposite direction, towards and beyond Orihuela, the Segura flows through a broad belt of orange groves, fruit and vegetable gardens of extraordinary fertility. This large river, which, at 100 miles from the sea, may almost be regarded as a navigable stream—and is used for bringing down large quantities of timber from the mountains of Segura to the railway station of Minas—is so amply tapped for irrigation purposes throughout its course, that there are seasons when at the mouth it is perfectly dry, and discharges no water at all into the sea.

It is around the capital of the province, in the celebrated *Huerta de Murcia* (Orchard of Murcia), that the irrigation is most extensive, and its effects most remarkable. The city is built on the banks of the Segura, in the centre of a plain of wonderful fertility, composed of a deep vegetable mould. In a comparatively narrow rocky gorge, at a distance of between 5 and 6 miles above Murcia, a huge dam called the *Parada*, 220 yards long, and from 40 to 55 yards in width—the construction of which is generally attributed to the Moors, and by some to the Romans—has been thrown across the stream. This dam raises the water to a height of 25 feet, and turns it into two large irrigation canals on both

banks of the river, from whence again it is distributed among twenty smaller channels, and conveyed, at different levels, to a distance of upwards of 20 miles down the valley, receiving some addition on the way from small branch streams. The water from the Parada irrigates an area of about 26,000 acres of richly cultivated land, which produces four different crops or more per annum.

In the Garden of Murcia the water is not separately bought or sold, but the right to the use of it passes with the ownership of, and is inherent to, the land. The Huerta is divided into two principal jurisdictions—one embracing the land and water north, and the other that south of the Segura river; and these, again, are subdivided into twenty minor jurisdictions, corresponding to that number of irrigation canals, each of which is managed by two representatives (*procurasdores*) of the landowners, who settle all minor disputes. All disputes involving questions of general interest are submitted to a tribunal composed of seven umpires, of whom five must be selected from amongst the *procurasdores*, and the other two from the superintendents of the canals, who are publicly elected every month. The Alcalde, or Mayor, of Murcia presides over this tribunal, and the whole management of the two principal canals, north and south of the river, is under the control of the municipal corporation.

Next in importance to the Huerta de Murcia is the *Huerta de Lorca*, a large town about 30 miles west of Murcia. The water is supplied by the river Guadalantin. An extensive area is irrigated; but the water being insufficient for garden cultivation, it is chiefly applied to cereal crops, which only require intermittent irrigation.

The system of distribution differs entirely from that at Murcia. The water is private property, and is sold from day to day by public auction, about five-sixths by measure, the quantity being gauged by the size of the outflow, and the rest by unity of time. Towards the end of the last century great efforts were made to increase the supply of water in this district, and two extensive reservoirs were formed, by constructing the dams known as the *Pantano de Lorca* and the *Pantano de Val de Infierno*. The first of these was a gigantic construction, 170 feet high and 500 feet long, built externally of large blocks of ashlar, and internally of coarse rubble, which, after it had stood for about seven years, gave way in 1802, and caused a calamitous loss of life, for the rush of water down the narrow valley was so great, and extended to such a distance, that it destroyed a great part of the town of Lorca. The Pantano de Val de Infierno has been so neglected that it has now been entirely filled up with silt, and rendered useless.

The Author describes lastly the *Pantano de Almansa* in the province of Albacete, which supplies water for the irrigation of only about 1,600 acres of land, but is noticeable as being the most ancient work of the kind in this part of Spain. It is 66 feet high,

and forms a semicircular wall 33 feet thick at the foot and 13 feet at the top; it is embedded at both ends in natural rock, and is supposed to have been built in the fifteenth century.

O. C. D. R.

On various Subjects relating to the Suez Canal.

By M. de Lesseps.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1137.)

1. *On the Maintenance of the Harbour at Port Said.*—The results of two years' dredging at the entrance of Port Said have been previously given.[1] After a storm which occurred in January last, soundings were taken at the mouth of the entrance channel, which showed that the dredging operations had fully maintained the required depth of water. Lately large vessels—as, for instance, the "Serapis" (4,582 tons), and the "Raleigh," drawing 26 feet of water, passed through the Canal without difficulty.

2. *Currents in the Canal.*—From Port Said to the Bitter Lakes the current flows at the rate of 1 foot per second, or about $\frac{3}{5}$ knot per hour: from Suez to the Bitter Lakes the current runs nearly 2 knots per hour. The current flows from Suez to the lakes when the tide is rising, and in the opposite direction with the falling tide. Between Port Said and the Bitter Lakes the direction of the current in the winter is towards the Mediterranean sea, on account of the excess of tidal waters brought into the lakes: in summer the current is reversed, having to supply the loss of water in the lakes due to evaporation.

3. *The Influence of the Canal on the Climate.*—From 1864 to 1870, rain was only noticed to fall once a year; now the dews are much heavier, and rain falls at least twice a month. Vegetation is increasing, and the climate of Suez appears to have altered, as the heat in summer is less complained of.

L. V. H.

On the Bitter Lakes of the Isthmus of Suez. By M. de Lesseps.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1133.)

Two years ago the Author expressed his views on the formation of the bank of salt in the middle of the Bitter Lakes on the Isthmus of Suez,[2] and this forms a continuation to that communication. It was supposed that the filling of these lakes would take a long time on acount of the evaporation and absorption

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 362.

[2] *Vide* Comptes rendus de l'Académie des Sciences, vol. lxxviii., p. 1740.

that would occur in their basins, dried up for centuries; but the whole space, amounting to about 1,962,000,000 cubic yards, was filled in the interval between the 18th of March and the 24th of October, 1869. The saturation of the waters with salt increased rapidly at first, and soundings showed that the bank of salt was being dissolved; but recent observations indicate that, though the bank continues to diminish, the waters, though subject to the combined effects of evaporation and saturation, are becoming less salt. In the six years that have elapsed since the lakes were filled, the bank of salt has been reduced by 78,480,000 cubic yards, or a weight of salt has been dissolved amounting to 88,500,000 tons. Analyses were made of the water in October 1872, and in July 1874; and whereas the soluble residue, in 1872, due merely to the dissolving of the salt deposit, should have been 123 lbs. per cubic yard of water, it only amounted to 120 lbs. The evaporation was accurately measured during the filling of the lakes, and it varied between 0·12 inch and 0·18 inch in twenty-four hours; and assuming it at only 0·08 inch, the total substance in solution should have been 170 lbs. per cubic yard of water, instead of 120 lbs. Though the bank of salt continued dissolving between 1872 and 1874, the analysis made in 1874 showed that the water was less salt than in 1872, the substance in solution weighing only 111 lbs. per cubic yard of water. The weight of chlorine, which is a more accurate measure of the salt in the water, was, by analysis, $65\frac{1}{3}$ lbs. per cubic yard in 1872, and only $61\frac{2}{3}$ lbs. in 1874. It is evident, therefore, that, as in spite of evaporation and the dissolving of the salt bank, the water becomes less salt, a current of fresher water must be flowing in and taking the place of water saturated with salt, which flows to the sea, and this action tends to reduce the saltness of the waters of the lakes to that of the sea. These results demonstrate that large expanses of salt water, at a considerable distance from the sea, can be prevented from becoming more salt, and from gradually drying up, by a comparatively small channel communicating with the sea, provided the channel is made deep enough to allow the concentrated solution to flow out. These conclusions are valuable at the present time, as showing that if, as has been proposed, the low-lying deserts of Algeria and Tunis were converted into lakes, only a moderate channel of communication with the sea would be necessary to provide against their being dried up by evaporation.

L. V. H.

Drainage of Berlin. By M. Mille.

(Annales des Ponts et Chaussées, vol. xii., p. 501, 1 pl.)

Berlin is a town of comparatively modern growth. In the year 1686 it contained only twenty thousand inhabitants, and now its population is about one million. Situated on a plain of sand, on the banks of the Spree, it spreads over 15,400 acres, of which only

6,300 acres are covered with buildings. As regards drainage, Berlin has remained in a primitive state during the enormous growth of its population. A great part of the supply of water has been obtained from pumps which, situated at intervals along the streets, draw the water from the strata of sand; a portion only having been furnished by an English water company, which drew its supply from the Spree above the town. The roads, badly paved and without proper footways, were bounded by ditches, as much as 2 feet 7 inches in depth, conveying the drainage of the streets and dwellings to the Spree, and crossed by flagstones or planks. Herr Hobrecht was intrusted with the charge of designing and carrying out a complete system of drainage. It was determined to convey the drainage from the houses and roads through sewers, and to deposit it by irrigation on the land. By an order of the 14th of July, 1874, as soon as the sewer is completed along a street, it is incumbent on the householders to connect their tenements with it by a drain 6 inches in diameter, which serves to carry off the rain-water, slops, and the discharge from the waterclosets; but no solid matter, cinders, or house refuse is allowed to pass down the drain. All cesspools are to be abolished, and waterclosets universally employed. The kitchen sink is provided with a grating, and a siphon and clack valve prevent the return of sewage gas through the house-drain; and the rain-water pipes are terminated by a siphon arrangement to arrest all solid débris washed off the roofs. Another order of the 4th of September, 1874, deals with the water supply, for the town authorities have purchased the waterworks, and an abundant supply is to be furnished to every house. The drainage and water supply are compulsory on the householders; and the annual amount required for paying off by degrees the capital expended on the works, together with interest and the cost of maintenance, is to be defrayed by rates levied on the householders. The drainage of the roads is to be effected at the same time; the gutters will discharge the water into earthenware pipe drains, 9 inches in diameter, laid along both sides of the road. They are connected with the secondary sewers, formed of stoneware pipes, 18 inches in diameter, or egg-shaped brick culverts, the width of which is two-thirds of the height. The secondary sewers lead into the egg-shaped main sewers, built of brick, 4 feet 4 inches wide, and 6 feet 7 inches high. There are receptacles for intercepting the solid matters from the streets, and ventilation is obtained through man-holes connected with the main sewers. There being no fall, and the water-level being near the surface, it is necessary to have separate sewers for the different districts. The population on each bank of the river is nearly equal; but Frederickstadt is most densely inhabited, and there the works are completed. The double-acting pumps will lift the liquid sewage 69 feet, and send it 8 miles in two iron pipes, 3 feet 3 inches and 2 feet 5½ inches in diameter respectively, to Marienfelder, where it is to irrigate 2,035 acres of land for the culture of vegetables, root crops and fodder, a plan already tried successfully at Thiergarten. On the left bank of the river there are two

pipes, each 3 feet 3 inches in diameter, for conveying the sewage, after it has been raised 98 feet, to the estate of Falkenberg, 1,818 acres in extent, and 8 miles distant. Five 400-HP. engines are to be employed for dealing with the sewage, the quantity of which is estimated at 22,000,000 gallons a day. There are also two pumping stations, one on each side of the river, in the centre of the town, for raising the sewage of the low portions of the town and transmitting it to the pumping stations on the outskirts. The cost of the works is estimated at £1,600,000, of which £400,000 have already been expended on the drainage of Frederickstadt; and it is calculated that the work will be completed in ten years.

L. V. H.

On the Drainage of Düsseldorf. By H. Ebner.

(Zeitschrift des Vereines Deutscher Ingenieure, vol. xx., p. 240.)

After discussing various systems of drainage for large towns, the Author proceeds to describe these works, carried out under his direction, though at present only partially completed. The town being situated on the banks of the Rhine, the sewers discharge into the river below the town, the river Düssel and other streams in the vicinity being made use of for flushing.

It was at first proposed to construct a main low-level sewer, running parallel with and contiguous to the main stream, into which the sewage could be collected by a number of minor sewers intersecting the town, and laid at right angles to the main sewer. As it was feared that it might become overcharged, three main sewers were laid at different levels, parallel with the Rhine, a junction being effected some distance below the town to discharge into the river at a low level, whereby the chances of back flooding are reduced. Each of these sewers can be shut off. Should the low-level sewer become drowned during an excessive flood, the mid-level is so built that it can act as a temporary reservoir, and can be emptied by a side pipe direct into the Rhine. Only the mid-level of these ducts has as yet been finished.

The sewer invert at its main outlet is 4·9 feet below the lowest known stream-level, 14·7 feet below the mean water-level, and 30 feet below high-water mark. The sewer mouth is therefore always under water.

The falls of the main levels commence at the upper end, with a gradient of 1 in 100, changing to 1 in 28; through the town they are only 1 in 3,000, 1 in 2,200, and at the outlet 1 in 660. The latter gradient was adopted because it may be necessary at some future time to prolong the outlet sewer and shift the mouth much lower down stream—to Golzheim. The waters of the Düssel used for flushing are stored by a weir, and it is expected that the large quantity available from these sources will compensate for the flat gradients of the sewers.

The sewer sections vary from 5·9 feet high and 3·94 feet broad to 2·95 feet high and 1·97 foot broad, being egg-shaped, excepting the union or outlet duct, which is circular. The invert is of glazed bricks, which are unaffected by the action of acids. These are perforated, and, in the lowest part, laid dry so as to permit of the inlet of land drainage.

The crown arch of the sewer is of kiln-burnt bricks, costing 48*s.* per thousand in Düsseldorf. The mortar consists of 1 part of cement to 4 of sand, and is economised by keeping the joints of the brickwork as close as possible. The conduction of the sewage from the houses is effected through stone-ware pipes. Ventilation shafts are occasionally erected, covered by gratings, and at every 600 feet there are access shafts for repairs and cleansing. Hanging doors are also provided to prevent back flooding.

D. G.

On Boring with Hollow Rods and a continuous Current of Water.[1]

By H. Pieler.

(Oest. Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 256.)

The method of flushing out the detritus produced by the cutting tool, has been for some years adopted by the Aalborg Company for deep well boring; and at the Vienna Exhibition a bore-hole had been put down to a depth of 1,206 feet in the comparatively short time of sixty-two days, but at that period the method was not applicable to loose ground, where lining tubes are required, and was only adopted for holes of small diameter. Recent improvements in the apparatus have, however, rendered the method of more general application, and the results obtained by the company in Holland and in Westphalia, by Herr Przibilla, of Cologne, show it to be a decided advance in this particular branch of mining technology.

At Niederbardenberg, in the Wurm coalfield, two bore-holes have been put down by Herr Przibilla, for the purpose of examining the strata overlying the coal-measures. The first of these was bored to a depth of 460 feet in three working days, and the second to 540 feet in five days. The ground consisted chiefly of watery quicksand, with a few bands of gravel and clay. The diameter of the holes at starting was 4·33 inches and 4·72 inches, which was gradually reduced to 2·16 inches. The hollow boring-rod was made of wrought-iron gas-pipe of the same diameter as that required for the hole, so as to serve as a lining tube. Water is introduced through the rod, flows to the working face, and returns to the surface laden

---

[1] This appears to be a modification of Fauvelle's plan, rather than a perfectly new method. Another Paper on the same subject by H. Wagner, "Zeitschrift für das Berg-, Hütten- u. Salinenwesen," vol. xxiv. p. 1, has also been used.—H. B.

with the mud produced by the cutter, by the annular space left between the outside of the tube and the side of the bore-hole, the pressure of the current relieving that of the ground against the tube, which is, in a manner, kept floating in water, so that it may be freely moved up and down by the boring lever. When the tube becomes jammed in the ground it is allowed to remain as a lining, and a similar one of smaller diameter is introduced for continuing the boring, the muddy water being then discharged through the space between the two tubes. The lower end of the tube carries a cutting tool, chisel-edged or otherwise, according to the nature of the rock to be traversed, but always so arranged that water may pass freely to the face. The cutter being rivetted to the tube, it was necessary to withdraw the latter when the diameter of the hole was reduced; an operation attended with considerable loss of time. To obviate this it is proposed in future to fix the cutter to the tube by a smooth conical head in such a manner that it can be detached by a blow from above without its being necessary to withdraw the tube. Thus when it becomes requisite to reduce the diameter of the hole the tool may be driven out by the head of the new rod, and pushed away to one side. The upper end of the rod is connected with the force-pump by an india-rubber tube, which allows freedom of motion in every direction. The force-pump, of English manufacture, had a steam piston of 5·11 inches and a pump of 3 inches diameter, making a stroke of 6·3 inches. It is absolutely necesssary to keep up a continuous flow of water while boring, otherwise the tube and cutter are likely to stick fast in the mud deposited. Whenever, therefore, it becomes necessary to break the connection with the pump, as, for instance, when screwing on a new length of tube, the boring must be stopped and water forced through the rods until it comes up perfectly clear. The velocity of the current while boring is a matter of practical experience which is easily learnt from the ease with which the tube can be moved, and from the indications of the effluent stream, which should be thick and muddy. At the borings in question the average quantity of water used was from 8 to 13 gallons per minute, and the velocity of efflux from 7·8 to 11·8 inches. The pressure of water in the pump under normal conditions of working did not exceed 3½ atmospheres. The water, after the mud has settled, is pumped back again for further use, about 10 per cent. additional being required to make up the loss. Taking these conditions as a guide, it will be found that a hole 11·8 inches in diameter would require about 33 gallons per minute, a quantity that, with good settling arrangements, will require only from 2 to 2·5 gallons of clean water per minute to replace the waste. The actual consumption of water in the two borings, as well as of coal burnt by the pumping-engine boiler, is given by Hérr Wagner as follows:—

	Water.	Coal.
Dufferheide.	5,000 cubic feet.	25 cwt.
Niederbardenberg . . .	7,800 „	45 „

As a general rule, the holes may be made smaller for equal depths than is usual in the older method, as the successive tubes can be used with very small difference of diameter. In one instance a hole started at 7·20 inches diameter was diminished as follows: 7·20, 6·18, 5·11, 4·13, 3·34, 2·59, 1·92, 0·78 inches. The deepest hole in hard strata bored by this method was 590 feet in Jurassic limestone, which was effected without difficulty, but no particulars as to time, &c., are given.

The Aalborg Company undertake contracts for borings in the following manner:—The whole of the apparatus, with a superintendent, are supplied at a rate per day, without any guarantee as to work done. The rate of hire varies according to the diameter of the hole—from 27*s.* per day and night for holes from 3 to 6 inches to 40*s.* 6*d.* for holes from 18 to 24 inches. Herr Przibilla, on the other hand, undertakes borings by contract at the price of about 50*s.* per mètre.

H. B.

On the Boring of Artesian Wells by a Water Jet.

(Berg- und hüttenmännische Zeitung, vol. xxxv. p. 66.)

This article contains details of the results obtained by the new Copenhagen well-boring company in the years 1873–74 in Holstein, Denmark, and Sweden, from which it appears that seventy-two holes were bored by this method, varying from 23 feet to 558 feet in depth, making a total of 9,400 feet, in nine hundred and sixty-eight working days, giving an average of 9·7 feet per day. The cost is said to be—

	s.	*d.*	
For wages and maintenance of machinery	7	4	per yard.
For lining tube 1·73 inch in diameter	2	9	"
	10	1	"

The first item is calculable upon the basis of 24*s.* per diem for the wages of four men and the maintenance of the machinery.

Of the above number of seventy-two wells eighteen, or 28 per cent., were failures; thirty-one, or 43 per cent., formed true artesian or flowing wells; while the remaining twenty-three required pumping. At Kiel twenty-two similar wells have been bored during the last six months; fourteen of these overflow, five others require pumps, and three have failed. The yield of seven flowing wells in the same place, which amounted to 752 cubic yards per diem in January 1875, diminished in June to 607 cubic yards, or a reduction of 19·3 per cent., owing to the supply being tapped by other borings in the neighbourhood.

The great obstacle to the use of this system in the alluvial plain of North Germany is the presence of boulders in the sand and

gravel strata, often of considerable size. Two methods are given for their removal. When small, a chamber is flushed out by the water jet at the bottom of the hole, so that the stone may be pushed to one side, and allow the boring tube to pass; but when a large boulder is encountered the boring tube is withdrawn to a safe distance, and a dynamite cartridge is lowered and exploded on the top of the stone, which is thereby usually sufficiently shattered to allow the fragments to be removed by the water jet.

H. B.

On Hydraulic Gold Mining in California.

By Ed. Sauvage.

(Annales des Mines, 7th series, vol. ix., p. 1.)

After noticing, at some length, the existing literature, in French and in English, on the great deposits of gold-bearing gravel in California, and the methods of working them, the Author passes to a general description of their position and character.

They occur at intervals on the western slope of the Sierra Nevada, through an extent of 7° of latitude; and generally present themselves in the form of hills, frequently situated on the summits of other hills, and in several districts capped by beds of volcanic matter—lava, basalt, and ashes—from 130 to 165 feet thick. The excavations made by miners show that they do not generally rest on level platforms, but fill, rather, a series of depressions or valleys, hollowed out in the underlying schist or quartzite. In some instances the "rim rock," forming the border of the basin filled by the deposit, is as much as 147 feet above the lowest adjoining part of the "bed rock," on which it rests.

The deposits themselves consist of a succession of irregular beds of sand, gravel, clay, and fragments of rock; for the most part horizontal, but frequently showing indications of false bedding, an appearance commonly met with in deposits of any kind formed in a rapid current.

At the base, and resting immediately on the bed rock, is found what is termed the "blue gravel," of a thickness varying from an inch, or less, up to 40 or 50 feet, and consisting of a strongly cemented bluish-coloured mass of coarse sand and rolled pebbles of all sizes, frequently larger than a man's head. The blue gravel is in some places so strongly cemented together as to form a veritable conglomerate, the "blue cement."

Next to the blue gravel there is frequently as much as 33 feet of "red gravel," composed of similar materials, but reddish in colour; and above this again come thick masses of gravel and sand, the "top gravel," whitish or yellowish in colour, and also more or less strongly cemented together. Towards the sides

there are frequently found beds of soft white pipe-clay, and of running sand. The total thickness of the auriferous deposit amounts in some instances to from 490 to 656 feet. The lowest beds are the richest. The average yield by the present methods of working is, from the blue and red gravels, 2*s.* 5*d.* per cubic yard, or from the whole mass of the alluvium, about 10·8*d.* per cubic yard.

The deposits are shown, by the fossil leaves and other plant-remains they contain, to be of the pleiocene age, and are apparently alluvial sands and gravels filling the valleys of ancient pleiocene rivers. The theory of their formation, suggested by the officers of the State Geological Survey, is that in miocene or early pleiocene times the rivers flowing down the western slope of the Sierra hollowed out these valleys in the primary and metamorphic rocks that then formed the land surface.

The subsequent elevation of the "Coast Range" during the pleiocene period reduced the slope of the valleys, and caused them to fill up with alluvium, forming a great plain, which was again covered in many districts by sheets of basaltic lava, thrown out by the volcanic eruptions which there marked the close of the pleiocene epoch. Lastly, in post-pleiocene times, a further elevation of the range of the Sierra Nevada has given to the horizontal lava beds a uniform slope towards the sea, and caused the cutting out of a new system of valleys, quite distinct from and independent of the older pleiocene valleys that are now found filled up with alluvium. The existing valleys are on the average 1,300 or 1,650 feet deeper than those of the older series.

The portion of the gold-bearing district which the Author more especially describes, and of which he gives a map, is the valley basin, or drainage area, of the Yuba, immediately to the north of the line of the Central Pacific railway.

The mode of working the sands and gravels is to disintegrate them by powerful jets of water, which first break up the mass, and then wash its fragments down long inclined wooden troughs, or "sluice-boxes." The bottom of these troughs presents a series of hollows, in which mercury is lodged. This retains the particles of gold, more or less completely, while the sand and stones are carried away by the current. The gravel is frequently loosened and broken up, by blasting, before the water jet is turned on it; and in some cases, where the cemented masses are very hard, they are crushed by stamps. As the lowest and richest portions of the alluvium are in most cases below the level of the "rim rock," it is necessary, in order to be able to work out a deposit to the bottom, to pierce an inclined tunnel from the side of the adjoining recent valley under the lowest part of the mass.

The system of hydraulic mining was first introduced at Yankee Sim, in Placer County, in 1852, but has only in recent years attained to its present vast development. The amount of water required being very great, the first thing to be done in establishing a hydraulic mine, is to construct a large reservoir, at such a height

above the level of the mine as to yield a supply at sufficient pressure.

The particulars of some of these reservoirs in the upper part of the Yuba Valley are:—

——	Greatest Height of Embankment on inner side.	Area.	Height above sea level.
	Feet.	Acres.	Feet.
Eureka Lake	69·8	197·5 to 296·5	6,560
Meadow Lake . . .	39·3	296·5	7,550
Rudyard Reservoir . .	80·3	..	..
Big Cañon Reservoir .	65·6	..	..

The Eureka embankment is built in equal proportions of blocks of granite, laid dry, and of rammed earth. Its volume is 10,856 cubic yards. The inner face is lined with pine planks, 3 inches thick, nailed to beams 12 inches by 12 inches, and caulked at the joints.

The embankment of Meadow Lake is similar; the outer face being a dry stone wall, with a batter on each side of 1 in 7, and tied together, through half its length, by two ranges of round timbers, 10 inches in diameter, built into it transversely, at 9·8 feet apart. The inner side is formed of a mass of gravel, sand, and clay, with a slope on the face next to the water of 28° to 33°. The embankment consists of 9,810 cubic yards of masonry, and 15,696 cubic yards of earth.

The Rudyard and Big Cañon reservoirs are formed of a cribwork of logs, 1 foot to 2 feet in diameter, filled with stones, and lined on the inner face with planks, which are again covered with clay.

The usual slope of the canals, or "ditches," leading the water from the reservoir to the mines, is about 10 feet per mile. They are provided at intervals with discharge sluices, by which they may be emptied rapidly in case of accident. The Eureka ditch, which with its branches is more than 40 miles in length, has a width of 5·6 feet, a depth of water of 33 inches, and a slope of 16 feet per mile; and delivers 192 cubic yards per minute. The ditches are carried across valleys either by timber aqueducts, often of great height, or by siphons. The aqueducts are generally built of 1½-inch boards, supported by frames of light timbers, 4 inches by 4 inches, or 4 inches by 3 inches, placed 30 inches to 36 inches apart, and are carried at intervals by trestles. They last, at the most, ten or twelve years.

The Magenta and National aqueducts, on the line of the Eureka ditch, are respectively 1,542 feet long by 131 feet high, and 1,805 feet long by 65·5 feet high. The water channel in each is 6·8 feet wide by 14·9 inches deep, and slopes 1 in 100. It is

formed of planks 7·5 inches thick, carried by trestles 30 feet apart between the centres. The side-pieces of these trestles consist each of a single stick.

As an example of the siphons used to carry the water across valleys too deep to be bridged by trestle-work, that over the north fork of the river Feather, near Cherokee (Butte County), is described. It is 14,114 feet in length by 30 inches in diameter, and descends at its lowest point to a depth of 830 feet below the outlet. The discharge, with an effective head of about 49 feet, is 82 cubic yards per minute.

The water supplied by the ditch is delivered into a deep wooden tank, at a sufficiently high level, and as near to the mine as possible; and is led from this to the working places through thin riveted sheet-iron pipes. The diameter of these is about 22 inches for a flow of 231 to 308 gallons per second, and 30 inches for a flow of 462 gallons per second; and their thickness is, for a diameter of 22 inches and a head of water of 147 feet, No. 16 gauge (0·065 inch); for a head of 147 feet to 246 feet, No. 14 (0·083 inch); and for 246 feet to 328 feet, No. 12 (0·109 inch). For a diameter of 30 inches, No. 14 sheets are used up to a pressure of 147 feet of water; and No. 12 for pressures from 147 feet to 279 feet. For pipes 3·28 feet in diameter, and a pressure of 164 feet, sheets 0·24 inch thick are used. The tubes are tarred, by dipping in Dr. Angus Smith's composition. The main pipe conveys the water into one or more cast-iron "distributors," from each of which as many as four jets may be supplied, by secondary pipes 9·8 inches to 15 inches in diameter. The diameter of the jet is in many cases 6, or even 7 inches, and the nozzle is so fitted that the stream of water may be directed at pleasure on any point. Several of the arrangements in use are described. With the most improved form, a jet 6 inches in diameter, at a pressure of 435 feet, may be satisfactorily worked.

The tunnels for the outflow of water and gravel from the mine form another great item of expenditure in opening up a deposit for hydraulic mining. Tunnels 546 to 1,093 yards in length are found at many mines. Their slope is generally 3·5 to 4·5 per 100, and their section varies from 4·9 feet wide by 5·9 feet high up to 6·5 feet wide by 7·8 feet high for one line of sluice-boxes, or even 11·5 feet wide for two lines of sluice-boxes in the case of mines that have an ample supply of water for work all the year round, and have one line of boxes in use while the gold amalgam is being collected from the other. Care is taken to drive the tunnel at such a depth that it will pass well under the centre of the deposit, both in order to command its whole extent, and to avoid the beds of clay and quicksand that often occur near the sides. It is opened to the surface, when sufficiently far in, by carrying up from it either a slant or a vertical rise, or "chimney," through the bed rock and the gravel, until this becomes too loose to be worked through easily, and a pit, to meet the chimney, is then sunk from the surface.

The tunnel of the North Bloomfield mines is 2,515 yards long by from 5·9 feet to 8·2 feet wide, and was driven, in between two and three years, through hard schists and quartzites. Its cost was from 506*s.* to 519*s.* per yard. At French Corral a tunnel 984 yards in length and 7·5 feet by 7·5 feet in area was pierced, 1874, at a cost of 523*s.* per yard. Its slope is 4·8 per 100.

When the tunnel has been completed, and a communication effected between its inner end and the surface, by a shaft or an inclined gallery, the opening of the mine is commenced, by enlarging the top of the shaft by pick and shovel, and washing the loosened material away through the tunnel by a strong stream of water. This is continued, care being taken not to choke up the tunnel by throwing into it more gravel than the water will carry away, until a sufficiently large opening has been made to admit of the use of jets under high pressure. To avoid the risk of dangerous falls of the gravel, it is first worked away in steps of only moderate height; but when the workings have been so far opened out that falls of gravel cannot choke the entrance to the tunnel or do other damage, the height of the steps is increased. Even in fully opened out mines, however, this does not generally exceed 131 feet, though vertical faces 164 feet high, or more, are occasionally met with.

In regular working one or more nozzles, according to the available supply of water, are set up at such a distance from the face of gravel as to be beyond the reach of falling masses; and on turning on the water, jets 4·7 inches to 6·7 inches in diameter, corresponding to a delivery of 77 to 154 gallons per second, are launched against it with terrific force. The jet delivered from a well-shaped nozzle preserves almost perfectly its cylindrical form until it strikes the gravel, into which it soon cuts a deep hole, carrying down stones, sand, and clay into the line of sluice-boxes below. The hole is widened by suitably directing the jet, until the overhanging mass falls and is washed away by the stream. Lumps of conglomerate or of clay too hard or too plastic to be readily broken up by the water are divided by hand or by small charges of dynamite; and the blocks of rock occasionally found in the gravel are either heaped together where there is space for them, or are broken up and washed down the sluice-boxes in the same way.

Where the inner end of the tunnel is at some depth below the base of the deposit, the stream of water and gravel is led into it down a succession of cascades, as it is considered that the masses are better broken up in this way than by a single high fall down a vertical shaft.

The gravel is frequently loosened and thrown down by blasting, before the water jets are turned on, where it is too hard to be disintegrated economically by water alone, or where the working faces are too high, so that the nozzles for the jets cannot be safely put close enough to play on the face to advantage. An ordinary blasting charge, where the height of the working face is 82 feet

to 98 feet, would be 14,850 lbs. of gunpowder, or 2,530 lbs. of No. 2 dynamite (composed of 40 parts nitro-glycerine, 20 silica, 10 nitrate of soda, 20 resin, and 10 sulphur). This quantity, properly placed, would loosen and disintegrate 50,000 to 60,000 cubic yards of gravel.

The consumption of water varies from ten times to forty times the volume of the gravel worked; and it is estimated that the minimum amount that will carry the disintegrated materials down a line of sluice-boxes, inclined 4 per 100, is about seven times the volume of the gravel.

The consumption of powder varies in different mines, from only the small amount required to break up occasional lumps of hard conglomerate, or masses of rock, up to 1·1 lb. per cubic yard, or more.

The sluice-boxes, in which the gold is collected, extend from the working places through the tunnel, and as far as possible down the valley below, generally a total length of 1,000 to 2,000 yards. They are wooden troughs, 3 feet to 6 feet wide by 3 feet to 3·28 feet deep, and inclined from 3 to 9 inches in each 12 feet length (2·1 to 6·2 in 100). The least slope is used where the supply of water is abundant and cheap, and the greatest where water is scarce. A medium slope, of 4·2 per 100, is suitable in ordinary cases; and slopes of 3·1 to 3·5 per 100 give also good results. The bottom of the sluice-box is paved with stones or blocks of wood, about 10 inches in height, and is so set as to leave narrow interspaces, in which the mercury and the gold amalgam lodge. Wood paving, though it is more expensive and less durable than stone, is generally used in the tunnels, because the wooden blocks are more quickly removed, an operation which is occasionally necessary to collect the gold amalgam; and in the tunnels there is commonly only a single line of sluice-boxes, so that whenever these are emptied for cleaning, the working of the mine must be suspended. In the line of sluice-boxes, below the tunnel, several accessory arrangements are frequently introduced where there is sufficient available fall to admit of them. A simple vertical cascade, or a succession of such low cascades, are often added, and have a good effect in disintegrating the material; and where the ground has a sufficiently rapid sidelong slope, advantage is taken of it to get rid of the large stones, by running the stream through an inclined grating of old rails, or other heavy bars, spaced about 6 inches apart, down which the large stones roll, and are thrown out, while the smaller gravel and the water pass through. Several "undercurrents" also are generally introduced, where there is the necessary fall; these are large tables, or flat boxes, about 9·8 feet wide by 30 to 60 feet long, and set at a slope varying from 5·25 to 8 per 100. The bottom is covered with a series of transverse strips of wood, set so as to leave narrow intervals between them, or it is paved in some cases, like the sluice-boxes, with stone or wood blocks; the finer gravel and sand from the sluice-box, with part of the water, is drawn off through a grating in the bottom, and

distributed over the width of the table, from the lower end of which it falls into a deep box, where it unites again with the rest of the current, and from which a new line of sluice-boxes starts.

The charge of mercury for a line of sluice-boxes 1,640 yards in length, is 495 to 605 lbs.; and an additional quantity of about 100 lbs. per day is generally added at short intervals. A hundred flasks, or about 7,200 lbs., are considered a fair provision for a six months' campaign. The amalgam is collected from the upper part of the line of sluice-boxes once or twice a month, but the general cleaning of the whole length of conduit takes place only once or twice in the year. The amalgam is washed and treated with dilute sulphuric acid, and the mercury is then distilled from it in a cast-iron retort and used again. The gold is melted, and cast into ingots. The gold, which is frequently 96 per cent. pure (its principal alloy being silver), is re-melted at San Francisco, with gold from other districts containing more silver, so that the proportion of silver to gold shall be about 3 to 1. The alloy is granulated and treated with boiling sulphuric acid, which dissolves everything except the gold. This is washed with distilled water, compressed, and melted. The sulphate of silver, after separating any lead that may be mixed with it, is crystallised by cooling the acid solution; reduced by pouring over the crystals a concentrated solution of protosulphate of iron, and similarly washed, compressed, and melted.

The loss of mercury, in the most carefully managed mines, is 12·5 to 15 per cent. of the total quantity placed in the sluice-boxes, and the proportion of gold that is lost must be still greater. Several proposed means of diminishing these losses are discussed in detail. Particulars are also given of the arrangements of stamps used for crushing the "blue cement" and other hard masses of gold-bearing conglomerate; and the Paper concludes with a detailed account of the modes of working, the capital expenditure, working costs, and profits, of several of the principal mines. The total expense of working varies from 1*d.* to 3*d.* per cubic yard of gravel turned over; and about four-fifths of this may be taken as the estimated value of the water, or the amount paid for it when, as is often the case, it is bought from other mining companies; the cost of the actual labour per cubic yard, in one instance in which it is given separately, being only 0·024 franc, out of a total working cost of 0·178 franc or 13·5 per cent.

The produce per cubic yard varies from mere traces, such as 0·84*d.* in the "top gravel" worked at North Bloomfield before the tunnel there was completed, up to 1*s.*, 2*s.* 6*d.*, 3*s.*, or more.

W. H.

Experiments on the Production of Tellurium from the Transylvanian Gold Ores. By A. Hauch.

(Oesterr. Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 240.)

The ores produced by the mines of Nagyág and Offenbánya are remarkable as containing a comparatively large proportion of the rare element tellurium, which, although it has hitherto been of no commercial importance, has latterly been in some demand on account of a new application for the construction of thermo-electric batteries. The following experiments have been undertaken to discover a cheaper method of production than those heretofore in use.

The ore, as delivered for smelting, was found to be of the following average composition: quartz, 30 to 40 per cent.; carbonate of lime, 10 to 20 per cent.; carbonate and sulphide of manganese, 15 to 20 per cent.; alumina, 5 to 8 per cent.; galena, 5 to 8 per cent.; copper pyrites, 1 to 2½ per cent.; blende, 1 to 4 per cent.; and small quantities of cobalt, nickel, antimony, arsenic, tellurium, gold, and silver.

When such a mixture of minerals is roasted, a portion of the tellurium and gold are volatilised, and may be recovered in properly-constructed condensing chambers. The manganese compounds are converted into manganic oxide, while the greater part of the gold is reduced, so that about 50 per cent. of the total amount may be saved by amalgamation. By subsequent treatment of the roasted ore with weak hydrochloric acid, which can be done in wooden vats lined with lead, chlorine is generated in considerable quantity, through the action of the manganic oxide, and the whole of the valuable metals present, with the exception of silver, which remains in the insoluble portion, are converted into soluble chlorides. Any excess of chlorine produced in this operation is economised by condensation in water, which gives a liquor that can be used for redissolving the crude tellurium. The solution of chlorides obtained by this treatment is next cleared from lime and lead, which are precipitated as sulphates, by the addition of sulphuric acid. The separation of these sulphates is effected by subsidence and decantation, as filtration is found to present considerable difficulties.

Gold is next precipitated from the clear solution by the addition of a solution of sulphate of iron; and after filtration, tellurium, by the action of metallic zinc, which produces a black, muddy precipitate. This may, after washing with hydrochloric acid and rapid drying, be converted into crude tellurium by fusion, without any flux, in a porcelain crucible; but the product so obtained invariably contains lead, copper, nickel, and antimony, and it is therefore preferable to redissolve the first telluriferous precipitate in chlorine water, and subject the solution for a considerable time to the action of sulphuric acid, whereby tellurium in a high state of purity can be obtained.

The original residue of the chlorination treatment contains, in addition to silver as chloride, some gold in a soluble state. By the addition of sulphate of iron to these residues when in a moist condition, the gold may be reduced, and the substance is then fit for treatment by amalgamation; but fusion with lead, when it can be done, is generally preferable.

The following results were obtained in an experiment conducted according to the above principle: 14·5 lbs. of tellurium ore, containing 14 dwts. of gold and 13·9 dwts. of silver, were roasted for an hour and a half in a muffle furnace. The loss of weight was equal to 7·2 per cent., and 0·35 per cent. of gold and 3·8 per cent. of silver were computed as lost by volatilisation. The roasted ore weighed 14·3 lbs., of which quantity 13·2 lbs. were taken for subsequent treatment by chlorine. This was effected by mixing it with 10·4 pints of water, 6·8 pints of crude hydrochloric acid (25° Beaumé), and 10·6 ounces of concentrated sulphuric acid. The addition of the acid was attended with effervescence, owing to the rapid evolution of carbonic acid and chlorine.

After twenty-four hours, the solution was diluted by the addition of 6·8 pints of water; the whole contents of the dissolving vat were stirred well together and allowed to settle for two hours, when the clear liquor was drawn off. This operation was repeated three times, giving a total quantity of 2 gallons of liquor, which was then treated with a solution of green vitriol (3·5 pints of 25° Beaumé) in order to separate the gold. This was completely effected in twenty-four hours, and the resulting gold, after being washed, dried, and cupelled with lead, weighed 10·5 dwts. or 82·2 per cent. of the total contents of the ore treated—an amount that might have been increased to 90 per cent. if the washing of the residue had been more completely carried out.

The liquor remaining after the separation of the gold was next treated with 4·4 lbs. of commercial zinc. The black mud precipitated, after standing twenty-four hours, when washed, dried, and melted, yielded 19·3 dwts. of crude tellurium, or about 0·43 per cent. of the weight of the ore operated upon. The consumption of zinc was about 3 per cent. of the weight of the ore. The argentiferous residues were found to contain 2·5 dwts. of gold and 10·9 dwts. of silver. The final result, therefore, gave about 2 per cent. of gold in excess of that indicated by assay, while the loss of silver was about 8·9 per cent. These differences, especially that of the gold, the Author ascribes partly to the difficulty of sampling, owing to the unequal distribution of very rich minerals in the mass of earthy substances forming the ore, and partly to the irregular loss by volatilisation of the precious metals with the tellurium in the assaying processes, which is always observed with these minerals. The Author concludes by pointing out that this method is likely to be of considerable value to the Nagyág and Offenbánya mines in the event of a demand for tellurium arising on a large scale. H. B.

On the Manganese Ore Mines at Vigunsca in Carniola.
By H. Fessel.

(Zeitschrift des berg- und hüttenmännischen Vereines für Kärnthen, vol. vii., p. 355.)

The manganese ore of Vigunsca, belonging to the Carinthian Industrial Company of Laibach, occurs in the form of an irregularly stratified mass, varying in thickness from 3 to 12 feet, on the southern slope of the mountain of the same name, in the district of Radmannsdorf, Upper Carniola, about 25 miles north-west of Laibach. The bed of ore is interstratified in the schists of the Upper Trias (Werferner Series), and overlaid by the Hallstatt limestone, a higher member of the same formation. The deposit is known for about $1\frac{3}{4}$ mile along the strike in an east to west direction, and dips with the hill at an angle of about 35°, forming, apparently, an inclined basin between the Triassic and the Alpine coal strata which occur lower down the hill. The character of the ore varies to some extent, the general appearance being that of a mass of decomposed yellow clay-slate, carrying irregular strings and patches of dark-coloured manganese ores. The best portions, which are usually found nearest the roof, have a rough irregular surface, and are of a dark steel-grey colour when freshly broken. Stalactitic strings and crystals of calcite, produced by infiltration of water, are the only foreign minerals found in association with the ore. The average composition of the ore in an air-dried condition is as follows:—

Peroxide of manganese	26·09	} Metallic manganese . 31·40
Sesqui-oxide „ „	21·58	
Silica	18·87	
Peroxide of iron	8·10	
Alumina	3·11	
Carbonate of lime	5·90	
Magnesia	0·50	
Alkalies	1·67	
Water	13·72	
	99·54	

The proportion of peroxide of manganese, and, consequently, of available oxygen, is too small to allow of the ore being used for the production of chlorine; it is therefore utilized for the production of highly manganiferous pig iron by smelting it in admixture with spathic iron ores. The richest spiegeleisen, or ferro-manganese, in the Vienna Exhibition, containing 35 per cent. of manganese, was made from this ore in the company's blast furnaces at Sava and Jauerburg. Latterly ferro-manganese containing 50 per cent. of manganese has been produced, which is principally exported to France, Belgium, and England.

The mine is opened by a level about 200 fathoms below the outcrop, which has been driven on the course of the deposit for

about 45 fathoms, from which rise-headings have been put up for 36 fathoms, and united by intermediate levels, forming a series of pillars which will be subsequently removed, from above downwards. Care is requisite, in working away the ore, to equalise the amount of rich and poor ground broken, so as to obtain an approximate uniformity in the produce. The stuff thrown down from the upper workings to the level is loaded into trams, upon a railway brought out to the floors at the level-mouth. The carriage to the smelting works was formerly effected by sledges in the winter months, but the greatly increased demand for the ore renders such a method of conveyance totally inadequate for the present requirements. The shortest practicable line for a cart road from the mine to the bottom of the valley would have been about 2½ miles long, with an average gradient of 1 in 8, over ground liable to be swept by torrential summer rains and winter avalanches, rendering the cost of maintenance very large. The cost of a fixed inclined plane was also thought to be too great, having regard to possible variation in the character of the mine, which might lead to the sudden abandonment of the present workings and the opening of new ones. It was therefore decided to adopt a suspended or rope incline, which has been carried out on a new principle by the director, Ritter von Pantz. This consists in the use of a single strained rope, upon which the buckets travel, the tractive power for the return empties being applied through the medium of a pair of thin hauling ropes coiling upon conical drums.

The vertical distance between the ends of the line is 1,336 feet, which is divided into two sections, each being complete in itself with drum and breaks. The principal dimensions of these are as follows:—

	Upper Section.	Lower Section.
Length of line	241·7 fathoms.	297·7 fathoms.
Vertical distance	107·5 „	115·5 „
Horizontal do.	216·5 „	274·5 „
Angle of slope—		
Mean	26° 40′	22° 30′
Maximum	29° 15′	27° 30′
Minimum	22° 0′	17° 15′

In each section the guide rope is supported by timber stagings at three intermediate points, the middle one carrying the crossing place. This consists of a pair of edge bars of iron, 3 inches high and 0·6 inch wide, about 45 feet long, which are brought at either end, by a curved portion of 40-feet radius, into contact with the guide rope. The buckets, of wrought iron with hinged bottoms, are suspended by a hook carrying two grooved pulleys, which constitute the special peculiarity of the system, the groove of the outer one running on the guide rope, and that of the inner one on the rail at the crossing point. The capacity of the bucket is 5·18 cubic feet, equal to a weight of 4½ cwt. of manganese

ore. The diameter of the guide rope is 1 inch, and that of the hauling ropes 0·33 inch. The rope drums are conical, with ordinary lever breaks for stopping and reversing, besides an air fan which helps to equalise the travelling speed of the load over the varying inclinations of the different sections of the line.

The time occupied in the passage of the loaded bucket from the mine to the tipping-place in the valley is about eight minutes, and, as there are always two buckets on the road, it is possible to send down one hundred and twenty loads, or about 27 tons, in the shift of ten hours, or about 600 tons per month of twenty-four working days; but by working at greater speed, from two to two and a half times as much could be forwarded in the same time. Five men are required for the two sections—a breaksman for each, one helper for the lower, and two for the upper section.

The production of manganese ore was, in—

1873	2,375 tons.
1874	2,950 „
1875	3,800 „

The cost of transport of the ore from the mine to the works at Sava has been reduced by this method from 7*s.* 6*d.* and 9*s.* per ton to 4*s.*, of which amount about one-third represents the cost due to the inclines. The wear of the rope, although doing double duty (*i.e.*, the buckets travel over it in both directions), is very small, being barely perceptible after carrying a net load of 5,000 tons. The cost of the whole line was only about £800, although it was constructed in the winter, in a perfectly barren country, more than 4,000 feet above the sea-level, conditions involving considerable labour and trouble in the conveyance of the necessary material.

H. B.

On the Production of Salt from Borings at Schönebeck.

By H. Mehner.

(Zeitschrift für das Berg-, Hütten- und Salinenwesen, vol. xxiv., p. 11.)

The government salt works at Schönebeck were supplied, up to the year 1836, by weak brine-springs from three wells at Elmen, the brine of which was concentrated by graduation, or by spontaneous evaporation in the air, over brushwood before boiling down, the average production at that time being between 32,000 and 34,000 tons per annum. In 1837 the supply was augmented by saturating the brine with rock-salt from the deep-seated deposit at Stassfürth, a plan that was followed for about ten years; but since that time the supply has been kept up by strong brine derived from a deposit of rock-salt on the spot, which has been reached by numerous borings. The average annual production of salt during the last five years has fluctuated between 60,000 and

70,000 tons. The borings extend in a north-west to south-east direction for about 6 miles in the alluvial plain of the Elbe. The salt deposit, which is in two beds between the upper and lower members of the Bunter Sandstone series, is overlaid by the limestone of the Muschelkalk and the New Red Marl, the whole having an irregular dip to the south-west. None of these formations, however, appear at the surface, which is entirely covered by lignite-bearing tertiary strata, forming the flat ground by the river; so that the discovery has been entirely made by borings extending over a period of more than thirty years. Eleven holes were bored between the years 1840–71, which are described in detail. Of the whole number, three were abandoned either in the upper measures, or as not available for working; the successful ones being the following:—

Nos.	Period of Boring.	Depth.	Total Cost.	Average Price per Foot.	Average daily Advance.
	Years.	Feet.	£.	£. s. d.	Feet.
III.	1849–55	1,799	4,372	2 8 7	1·2
IV.	1855–60	1,850	6,876	3 14 5	3·1
V.	1859–62	1,558·5	2,962	1 17 0	4·8
VI.	1861–63	1,601·5	4,017	2 10 2	4·6
IX.	1864–66	1,337	2,823	2 2 0	4·4
X.	1867–71	1,548·5	4,608	2 19 5	..

In No. III. the boring was conducted entirely by manual labour; in the others steam power was used.

The arrangements adopted for drawing brine from the borings have been described at length in vols. vii. and ix. of the same Journal; the Author therefore merely summarises the principal points to be followed in works of this kind. These are:—

1. The protection of the purer portions of the bed of salt from those containing magnesian salts, by a coating of sand or concrete.

2. The strata immediately above the salt-bed must be coated with a casing of concrete, for the double purpose of providing a bearing for the lower end of the wooden lining, and for shutting off all chance of the infiltration of land water from above and the consequent introduction of sand and mud into the brine.

3. The protection of the bore-hole by lining-tubes throughout. The details of one of the borings, No. V., are given in illustration of these principles. The hole was bored 14 inches in diameter to a depth of 326 feet, and was lined with a 13-inch iron pipe, below which point it was reduced to 12¾ inches down to 500 feet, when a diameter of 8½ inches was adopted for the remaining 960 feet. A lower impure division of the salt-bed was then shut off by a packing of sand and concrete, after which a wooden packing was put into the hole immediately above the bed intended to be worked, and the hole lined for a length of 16 feet with concrete, or to within 2½ feet of the lower end of the lining-tube, which space was made

secure by concrete put down the hole, in order to get a tight joint. The details of the operations are to be found in the former volumes; in every case the hole was filled with concrete, which was allowed to set until it was sufficiently hard for reboring. The protection of the sides of the hole from erosion by the descending current of water was effected, in the lower portion, of 8½ inches diameter, by copper lining tubes of 7¼ and 7 inches bore, made in lengths of 10 feet, which were jointed by coupling-pieces 8 inches long, and secured by riveting and brazing. At the top they were strengthened by a brass collar, 1¾ inch thick, which lay in the shoulder formed by the offset from the smaller to the larger diameter at the depth of 500 feet. The lining of the upper section, in wood, is 10 inches in diameter and 1 inch thick for the first 500 feet, being in oak tubing, built up like a cask of staves, 10 feet in length; the remainder is in pine, bored out from the trunks of carefully-selected trees. The details of the tubing are summarised as follows:—

500 feet 9 inches	10-inch wooden tubing.
1 foot 6 "	Brass union piece.
519 feet 0 "	7¼ copper tubes.
440 " 3 "	7 " "
1,461 " 6 "	

The brine-lifting pumps are made of brass and copper tubes, whose diameter admits a space of about 2 inches within the lining tubes for the introduction of the dissolving current of fresh water. This gives a length of about 100 feet above the free level of the brine column, which in its turn is dependent upon the magnitude of the fresh-water column. The suction column, *i.e.*, the position of the foot valve of the pump barrel, is determined by the density of the brine. The working barrel of the pump is made one and a half time the diameter of the suction pipe, and the suction pipe about ½ inch larger than the latter dimension, so that the pump bucket may be easily withdrawn for repairs when required. When these dimensions have been fixed, the weight of the pump is calculated approximately, and that of the column of brine above the valve accurately, in order to determine the necessary substance of the copper tubes and brass collars, which are so chosen as to be subjected to a working strain of one-fourth of the ultimate resistance. The dimensions of the pump-work for the bore-hole in question, No. IV., are as follows:—

Suction pipe, 3·2 inches bore	1,100 feet long.
Pump barrel, 5 inches "	8 " "
Rising pipe, 5·5 inches "	400 " "

The screw collars of the suction pipes are 5 inches, and those of the rising pipes 7·8 inches in external diameter; the breadth of the annular space for the introduction of the working current

of fresh water is therefore 1 inch in the lower, and 1·2 inch in the upper part of the hole.

The following table gives the detail of the pumping arrangements in the holes which are now in working condition:—

Number of Bore.	Width within Lining Pipe.	Diameter of			Depth Bored to Salt.	Total Depth Bored.	Depths from which Pumps are now Drawing.	Depth to working Barrel of Pump.	Cost of Pump-work.
		Suction Pipe.	Pump Barrel.	Rising Pipe.					
	Inches.	Inches.	Inches.	Inches.	Feet.	Feet.	Feet.	Feet.	£.
IV.	$9\frac{1}{2}$	$3\frac{1}{2}$	$5\frac{3}{4}$	$6\frac{1}{4}$	1,675	1,850	$1{,}685\frac{1}{2}$	383–389	1,695
V.	$\left\{\begin{matrix}10\\ 7\frac{1}{2}\\ 7\end{matrix}\right\}$	$3\frac{1}{6}$	5	$5\frac{5}{12}$	1,480	$1{,}558\frac{1}{2}$	$1{,}487\frac{2}{3}$	443–449	2,055
VI.	$\left\{\begin{matrix}13\frac{5}{12}\\ 9\frac{1}{2}\end{matrix}\right\}$	$3\frac{2}{3}$	$5\frac{1}{2}$	6	$1{,}379\frac{1}{2}$	$1{,}601\frac{1}{2}$	$1{,}403\frac{1}{4}$	454–460	1,860
IX.	$\left\{\begin{matrix}12\\ 11\\ 7\frac{1}{2}\end{matrix}\right\}$	$3\frac{2}{3}$	$5\frac{7}{12}$	6	1,095	1,337	1,119	325–331	1,282
X.	$\left\{\begin{matrix}15\\ 10\\ 7\end{matrix}\right\}$	$\left\{\begin{matrix}3\frac{2}{3}\\ 3\end{matrix}\right\}$	$5\frac{7}{12}$	6	1,029	$1{,}548\frac{1}{2}$	986	293–299	1,780

The results obtained from these borings have not quite fulfilled the expectations of their projectors. A tolerably pure and strong brine, containing from $24\frac{1}{2}$ to 25 per cent. of salt, has been obtained from some of the bore holes, while others are different in this respect, *e.g.*, the brine of No. IX. only averages 21 per cent., and that of No. X. is often muddy. Experience seems to show that the yield is dependent more upon peculiarities in the bed of salt, than on the power of the pumping machinery; and that in order to obtain brine at a maximum of concentration, the pumping must not exceed a certain speed. This maximum has been attained in No. VI., which yields per minute an average of about 4 cubic feet of brine, containing 18·4 lbs. of salt per foot. When pumped at a more rapid rate the brine is weaker, and not so well suited for boiling down as that obtained at a lower speed. The Author then enters into details of the reasons which have led to the conclusion that the method of working by bore-holes is not susceptible of further development, and that the only way in which the increasing demand of the salt-works can be met, is by sinking a shaft to the salt-bed, which sinking was commenced in 1873.

NOTE.—The terms 'suction' and 'rising pipe' are used as in the original, but must not be confounded with these terms as applied to force pumps. The so-called suction pipe is mainly an inner well or cistern for the brine, and the rising pipe the loaded column above the pump bucket.

H. B.

On a New Method of determining with precision the Melting Point of Metals, as well as of other Materials, which are Bad Conductors of Heat. By Prof. Dr. Himly.

(Zeitschrift des naturwissenschaftlichen Vereins für Schleswig-Holstein, vol. iv. p. 1.)

The Author commences by pointing out that the precise determination of the melting point is of considerable importance, as a means of characterising bodies especially in the pure state. The connection between heat and the molecular constitution of bodies is little understood; it is not known, for instance, why platinum melts at the highest temperature of the oxy-hydrogen blow-pipe whilst mercury is liquid at $-38°$ F., or why calcium melts at a red heat whilst its combination with oxygen and chalk is almost as infusible as carbon.

The method of J. Löwe, described in Dingler's Polytech. Journ. Bd. 201, p. 250, consists in covering a platinum wire with the non-conducting substance whose melting point is required, and immersing it in a mercury bath connected up to a battery and alarum. On heating the mercury bath, which should be done slowly, the alarum will sound as soon as the temperature of the bath is such as to melt the non-conducting substance, and thus produce electrical contact. A mean variation of 7°·5 F. in twenty-four experiments has been found by Mr. C. H. Wolff, reduced to 0°·9 F. by altering the thickness of the wire employed. The Author considers this remaining error to be due to the difference of the heat-conducting power of platinum, and of the mercury in the thermometer placed in the mercury bath.

The arrangement proposed for metals and other electrical conductors is the following: An ordinary mercurial thermometer is silvered at the bulb, which is specially made pointed towards the end, and for a certain distance up the tube. A connecting wire being attached to it, this forms the scale.

A U-shaped glass tube of sufficiently large internal diameter is employed to contain the thermometer, which is placed with its connecting wire in one limb of the tube, while in the other a small cylinder of the metal, whose melting point it is desired to ascertain, is connected up to a leading wire and placed in the other limb. The leading wires are arranged up to a battery and electrical alarum. Beneath the U-shaped tube is a mercury or paraffin bath, heated by a Bunsen or other lamp; so that the temperatures of the metal and of the thermometer are both raised equally. When the temperature rises to that at which the metal melts, this will at once flow forward so as to complete, with the silver-covered thermometer, the electrical circuit; and the alarum will sound, the temperature of the thermometer being that of the molten metal. As this arrangement is only applicable to such metals as melt below the boiling point of mercury, for other metals a refractory material is employed in place of the

U-shaped glass tube, and a suitable pyrometer in place of the silvered thermometer.

For bodies which are bad conductors of heat and electricity, the Author proposes the following modification of the above arrangement: The non-conducting substance, of which the melting point is required, is melted and then allowed to cool, and as soon as the first crystal forms on the surface, the silvered thermometer is dipped in for a moment and is thus coated with a film of the substance. On cooling the thermometer is plunged into a metal bath containing mercury, to which is securely fixed a leading wire connected up to an alarum and battery, another connecting wire leading from the silvered thermometer. As soon as the mercury bath is heated to the melting point of the substance to be tested, the circuit will be closed and the alarum sound, the temperature of fusion being read off on the thermometer. For high temperatures the substance must be heated directly instead of through the medium of a bath. E. B.

On the Iron-bearing District of Ouelhassa, Algeria. By M. Pouyanne.

(Annales des Mines, 7th series, vol. ix., p. 81.)

Algeria contains numerous deposits of iron ore, of which that of Mokta el Hadid, the best known, was for many years the only mine from which any noticeable quantity of ore was obtained. The high prices, however, of 1872 and 1873 drew attention to other deposits in different parts of the country, of which the greater number are still more or less worked.

The deposit of Mokta el Hadid, and others similar to it, chiefly occurring in the province of Constantine, consists of beds of magnetic oxide and oligist, intimately associated with the older (palæozoic) rocks of the district. A second group, found chiefly in the province of Algiers, consists of numerous veins, in rocks of cretaceous age, of spathic iron ore, more or less altered, and intermixed largely, in many places, with ores of copper or of lead. Again, as a third type of deposits, may be classed those occurring principally in the province of Oran, in compact secondary limestones, believed to be of liassic age. Of these last, a remarkable group exists in Ouelhassa, in part of the commune of Tlemcen, on the coast of the Mediterranean, to the east of the river Tafna.

The iron-bearing limestone is compact, grey or bluish in colour, often sub-crystalline, and in many places showing no distinct lines of stratification. The ore contained in it is a peroxide of iron, fairly hard, with more or less manganese. It varies much in richness, but rarely contains any other gangue than carbonate of lime, and is almost entirely free from sulphur. It is not profitable to export any ores that contain less than 50 per cent. of iron.

The deposits are irregular in form and size, and at their

boundaries the ore generally passes insensibly into the limestone without any sharp division marking off the one from the other. The theory suggested of their origin is that the iron (probably originally in the form of carbonate) has been deposited in the mass of the limestone, by a process of substitution, from thermal mineral springs rich in iron and poor in lime.

Thirty-one distinct deposits, of more or less value, are described in the Paper, and their positions shown on the accompanying map of the district. They are nearly all within 2 or 3 miles of the sea, and many are quite close to it. The most important are those of Haouaria, at the eastern extremity of the district, and Dar Rih and R'ar el Baroud, near its centre.

At Haouaria one deposit only (marked No. 4 on the map) is as yet worked. It is an open quarry, 524 feet long by 23 to 26 feet wide, and with a maximum depth at present of 88 feet. The total depth of the mass of ore is not known; 20,000 tons of rich ore have been raised here, and will be carried down by a tramway 5,000 yards long, and with a fall of 650 feet, to the sea, at Camerata, where a shipping jetty is being constructed.

The deposits of Dar Rih and R'ar el Baroud lie near together, and form, with some others of less extent, by far the most important group in the district—that of Beni Saf. The want of a good shipping port has hitherto greatly hindered their development, only about 50,000 tons of ore having as yet been sent away. A port, however, is now about to be constructed, in a central position, at Mersa Ahmed, the necessary capital having been voted by the company owning the mines, and an application to the Government for permission to commence the work having been made.

A large amount of rich ore is to be got at both the mines above named, by open quarry working in the hillsides, as soon as means have been provided for sending it away; and the total quantity that may be obtained from these two principal deposits, as well as from those near them that appear (so far as yet explored) to be of less importance, must be practically unlimited. All the mines of the Beni Saf group lie within a radius of 2,750 yards from Mersa Ahmed. The outcrop at R'ar el Baroud occupies 15½ acres. It has not yet been worked, but five trial drifts and thirty-six pits, sunk in it at different parts, show that it consists throughout of pure, rich ore. The length of the railway planned to carry this to the shipping port is 3,500 yards.

It is impossible to form any reliable estimate of the quantity of workable ore in the entire district of the Ouelhassa, as the great majority of the known outcrops are either unexplored or explored imperfectly. And, besides, as the greater part of the district is covered by more recent rocks, through which the limestone crops up only here and there in small isolated patches, it may lie at a workable depth, and contain valuable ore in many localities where it does not appear on the surface.

W. H.

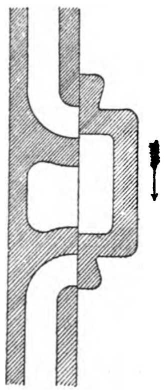
On Steam Welding Hammers (Schnellhämmer).
By Prof. Julius v. Hauer.

(Berg- und hüttenmännisches Jahrbuch, Leoben, vol. xxiv., p. 50.)

The Author, in treating this subject, states that the effect of the blow of a steam hammer, unless the valves can be worked with adjustable motion, is not produced by the non-expansive working of the steam above and below the piston, but is rather equal to the difference between the expansive effect which is produced and the compressive effect which is lost—less the friction; and he proves, by calculation, that there are certain degrees of expansion and compression by which the most effective blow can be produced.

If the piston and valves work in unison continuously, the effects of non-expansion and of counter-pressure steam neutralise each other during the up and down strokes. As the piston rises the valve descends, and expansion begins at the moment when the latter has descended far enough to close the lower port, as shown in Fig. 1.

Fig. 1.



The steam is now expansible until the piston has obtained a corresponding position. By reversing the movement, and with the same relative positions of piston and valves, counter-pressure steam begins, and lasts till the end of the stroke. The length of stroke, during which the steam acts non-expansively while the piston is rising, is exactly the same as that during which the counter-pressure steam resists its downward action, each neutralising the effect of the other. In the same way the counter-pressure steam during the up strokes counterbalances that during the down strokes, and the following periods of the division of the steam are of equal duration.

Underneath the Piston.

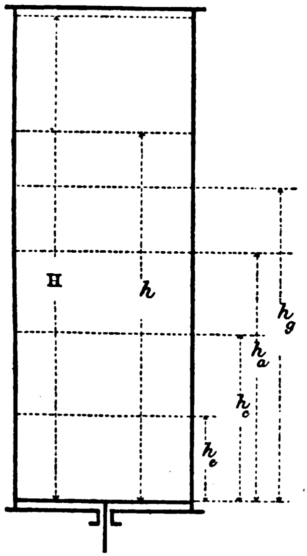
Non-expansion	during	up stroke	= counter-pressure steam	during	down stroke.
Expansion	"	"	= compression	"	"
Exhaust	"	"	= exhaust	"	"

Above the Piston.

Exhaust during up stroke	= exhaust during down stroke.
Compression " "	= expansion " "
Counter-pressure steam during up stroke .	= non-expansion " "

The strength of the blow and the length of the stroke are generally regulated by an adjustable manipulation of the valve. In Fig. 2, H is the greatest stroke, and h the length of stroke at

Fig. 2.



any other position of the valve. In this case during the up stroke expansion begins at $h\,e$, compression at $h\,c$, exhaust at $h\,a$, and counter-pressure steam at $h\,g$; during the down stroke $h\,g$ represents the point at which expansion begins, $h\,a$ compression, $h\,c$ exhaust, and $h\,e$ counter-pressure steam. The degree of expansion during the up stroke, and that of compression during the down stroke, is expressed by

$$e = \frac{h_a}{h_e},$$

and the degree of compression during the up stroke, and that of expansion during the down stroke, by

$$c = \frac{H - h_c}{H - h_g};$$

hence $$h_c = H - c\,(H - h\,g).$$

Let O represent the top, $f\,o$ the under area of the piston,

$(I-f)$ O the cross section of the piston rod, A the atmospheric pressure in units of area, p the tension of the feed and p' that of the exhaust steam in atmospheres, G the weight of the hammer, and R the friction. Then, accepting Mariotte's formula, the expansive or compressive action of the steam $= A p\, V \log. x$, in which $p\,V$ expresses the product of any tension, p, and the volume, V, which the steam, whether in expansion or in compression, obtains by the tension p, and x represents the degree of expansion or compression.

During the up stroke the expansive effect of the steam under the piston is expressed by $= A p\, f O\, h_e \log. e$, and the compressive effect of the upper steam by

$$A p'\ O\,(H-h_c) \log. c = A p'\ O\,(H-h_g)\, c \log. c.$$

During the down stroke the expansive effect of the upper steam is

$$A p\ O\,(H-h_g) \log. c,$$

and the compressive effect of the lower steam

$$A p\ f O\, h_a \log. e = A p'\ f O\, h_e\, e \log. e.$$

Subtracting from the expansive effect, the compressive effect and the friction 2 R H, there is obtained the effect of the blow

$$E = A\, O\,(H-h_g)\,(p-c\,p') \log. c + A\, O\, f\, h_e\,(p-e\,p') \log. e - 2\, R\, H.$$

The first two terms of this expression are nil, *i.e.* the hammer delivers no blow, firstly, when $c=1$ and $e=1$; or, in other words, when neither expansion nor compression is employed, as follows from the derivation of the expression E; secondly, when $c=\frac{p}{p'}$ and $e=\frac{p}{p'}$, *i.e.* when the compression beginning with the tension p' is continued up to the tension p of the counter-pressure steam and the expansion beginning with p up to the tension p' of the exhaust steam; in this case the expansive and compressive effects neutralise each other.

The value of the degrees of expansion and compression at which the effect of the blow will be greatest must lie somewhere between 1 and $\frac{p}{p'}$. To ascertain this it must be borne in mind that h_g depends on c and e, because during the up stroke the counter-pressure steam must begin at a certain position of the piston, if the hammer is to come to a standstill with the length of stroke h. The value of h_g may be obtained by adopting as nil the difference between the effect transmitted during the up stroke to the weight of the hammer and that exhausted by the resistance.

During the up stroke the following effects will be produced :—

By full pressure, and expansion of bottom steam,

$$A p\ f O\, h_e (1 + \log. e) = A p\ f O\, h_a\, \frac{1+\log. e}{e}.$$

By the tension p' of the exhaust steam through the space $h-h_a$

$$Ap'\,fO\,(h-h_a) = Ap'\,fO\,h - Ap\,fO\,h_a;$$

and by the atmospheric pressure on the piston rod

$$A\,(1-f)\,O\,h.$$

On the other hand there is lost, by the weight of the hammer and friction $$(G+R)\,h;$$

by the tension p' of the escaping steam above the piston through the space h_e

$$A\,O\,p'\,h_e = A\,O\,p'\,H - A\,O\,p'\,(H-h_g)\,c;$$

by compression of the top steam

$$A\,O\,p'\,(H-h_e)\log.c = A\,O\,p'\,(H-h_g)\,c\log.c;$$

lastly, by the counter-pressure steam

$$A\,O\,p\,(h-h_g) = A\,O\,p\,(H-h_g) - A\,O\,p\,(H-h).$$

If the actual effect produced, less the effect consumed, be supposed = nil, let the resultant equation be divided by A O, and let M be the terms, in which the factors h_a and H and H_g, as well as the values c and e do not appear, then

$$fh_a\left(p\,\frac{1+\log.e}{e} - p'\right)(H-h_g)\,(p - cp' + cp'\log.c) - M = O,$$

$$H - h_g = \frac{fh_a\left(p\,\frac{1+\log.e}{e} - p'\right) - M}{p - cp'\,(1-\log.c)},$$

$$(H-h_g)\,(p-cp')\log.c = U\left[fh_a\left(p\,\frac{1+\log.e}{e} - p'\right) - M\right],$$

hence $$U = \frac{(p-cp')\log.c}{p-cp'\,(1-\log.c)}.$$

If the equation for E be divided by A O, involving the above values $h_e = \frac{h_a}{e}$ then

$$\frac{E}{AO} = U\left[fh_a\left(p\,\frac{1+\log.e}{e} - p'\right) - M\right] + fh_a\left(\frac{p}{e} - p'\right)\log.e - 2\,R\,H.$$

The effect, E, will be the greatest by a given stroke, h, when h_a is nearly equal to h; nevertheless h_a must be perceptibly less than h, so that the exhaust port is sufficiently open towards the end of the stroke. Therefore h_a must be considered as a given quantity, and consequently E depends only on e and on the quantity U, which is a function of c.

Taking e as constant, E will be greatest when U is also greatest; and taking the differential co-efficient of U, according to c, as nil, then,

$$p - cp' = \sqrt{cpp'} \log. c.$$

The value of c, to which this equation corresponds, makes E, when e is given, a maximum.

On the other hand, taking c, and thence U, as constant, the quantity will be a maximum, as seen by the last equation for E, when the expression

$U p \frac{1 + \log. e}{e} + \left(\frac{p}{e} - p'\right) \log. e$ is greatest, and this is the case

when $$p - e p' = p\,(1 + \text{U}) \log. e.$$

If the maximum value of U be introduced, and e be determined, then there is obtained the degree of expansion e, which, with the above determined degree of compression, c, gives the absolute maximum, E.

The tension, p', of the exhaust steam is generally taken as 1·1 atmosphere. With this value as a basis, the above equations for different pressures of steam, p, give the following most advantageous degrees of compression and expansion in round numbers:—

For	$p =$ 2	3	4	5	6	atmospheres.
	$c =$ 1·3	1·7	1·9	2·2	2·4	„
	$e =$ 1·3	1·5	1·5	1·6	1·7	„

It appears that the degree of expansion varies only slightly: for ordinary steam pressure of between 3 and 4 atmospheres two-thirds feed and compression are applied to half the volume.

In steam hammers whose valves are fitted with an external apparatus for regulating the strength of the blow these degrees of expansion and compression must be adopted for that position of the valves which will give the strongest blow.

Hammers in which the valves are not so arranged with an adjustable motion to produce different lengths of stroke, give with equal dimensions considerably weaker blows than those fitted with the above apparatus. The only objection to the latter is, that the slide-valve is always liable to movement by shock, and the parts subjected to the shock are more apt to be damaged.

W. E. T.

On Work done by Divers in the Scharley Zinc Mines in Silesia.

By H. Freudenberg.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 214.)

On the 12th of April, 1875, one of the three large pumping engines at the Scharley mines was completely disabled by the failure of the top valve of the 39-inch plunger pump, apparently

by the jamming of a piece of wood between the valve and its seat. The engine, a double-acting one, being suddenly relieved from its ordinary load, under the full pressure of steam, by the water in the rising pipe falling back, ran away with a violent shock, loosening the wrought-iron catch-piece on the rod, which, together with a portion knocked off a bell crank weighing 30 cwt., fell upon the valve-box of the 39-inch plunger pump, and broke it into fragments. The two remaining engines, with 3-feet plungers, not being sufficiently powerful to keep the water down in the shaft, a small engine, with a 39-inch lift, which was being erected in an adjoining shaft, and was nearly finished, was put to work as quickly as possible. This was a compound beam-engine, with fly-wheel, the pump barrel being 262 feet below the surface. The main rod being of cast steel, 5·7 inches in diameter, and working continuously in tension, required loading at the bottom. This was to be effected principally by cast-iron plates fixed to the top of the plunger, but as not quite half of the requisite number of these had been attached before the water rose in the shaft, it became necessary to attach the remainder, amounting to 36½ tons, at a higher point, which could not be done without stiffening the rod by the attachment of wooden cheek-pieces. For this purpose two balks of timber, measuring 13·4 by 16·5 inches, with wrought-iron shoes, capable of adjustment by wedging, to prevent slipping, and twenty-two through bolts for strapping, were provided. Two divers were employed; one of them, having considerable experience in similar work, came from Poland, while the second had only recently been trained, by going through a course of special instruction in diving, in a reservoir belonging to a neighbouring mine, in accordance with the new system, which requires the formation of a special body of divers in every mining district in Prussia.

The preparatory work, of removing some wooden guides and cutting through several timbers in the shaft, to make room for the stiffening pieces, was performed between the 5th and 8th of May, the divers working at depths of from 16 to 85 feet, for periods varying from fifteen to sixty minutes at a time. On the 8th two screw bolts, 4 feet long, with 1-inch threads, were unscrewed and brought out in forty minutes from a depth of 85 feet. On the 9th and 10th the stiffening pieces were lowered into position by a winch, and provisionally fixed to the rod by lashings.

At this period an interruption took place, owing to an accident which was nearly attended with fatal consequences. The air-hose, having fouled the end of a piece of timber in the shaft, was torn while one of the divers was at work. He was, however, got up alive, but in an exhausted state, having narrowly escaped suffocation. On the following day, the whole of the air-pipes were carefully examined and tested under 3 atmospheres pressure, after which the work was resumed on the 12th and 13th, the men taking spells of from forty to sixty minutes, at a depth of 82 feet. Both men, however, complained of headache, and were not able to continue the work properly on the following days. The elder man

attributed the ill effects to the defective construction of the diving apparatus (Denayrouze), as he had not experienced anything of the kind when using Siebe and Gorman's diving dress. This latter was therefore brought from the Renard mine, in Poland, and was used from the time that the work was resumed, on the 19th of May, to its completion, on the 28th. On the former date the timbers were brought into final position, and six of the through bolts were fixed and screwed up in two turns of forty-five and sixty minutes. On the 20th fifteen bolts were put in and screwed up, in two turns of sixty-five and fifty-three minutes, the diver standing with one leg on the ladder and with the other in the bucket containing the bolts and nuts. On the same day the second diver was under water three times, for seventy, fifty-three, and eighteen minutes respectively. That these long spells of diving were accomplished without inconvenience to the men is entirely due to the correct principle of construction adopted in the English apparatus. In the Rouquayral-Denayrouze system a certain amount of vacuum must be produced by the lungs, to open the valve supplying fresh air, whereas in Siebe's apparatus the diver is as completely surrounded with air as if he were at the surface, and can breathe through both mouth and nose; and although the respired air is discharged into the same space, the capacity of the air-pump is so large that there is no difficulty in keeping up a constant supply of fresh air within the helmet.

On the 21st of May the whole of the nuts were tightened, and the lock-nuts attached and screwed up by the first diver in two turns, the first lasting two hours and the second forty-seven minutes.

The engine was started on the 25th of May, but the pump did not take water, owing to the valves not closing properly, and as it was only on the 28th that it began to work regularly.

The time occupied by the work under water was sixteen hours by the first diver, and ten by the second, during which comparatively short period a difficult task was successfully executed, and entirely without the aid of artificial light.

H. B.

Trials of the Consumption of Coal in a Steam-Engine.
By C. Ludwig.

(Technische Blätter, vol. viii., p. 29.)

These trials were made to test the guarantee given by the makers that an engine supplied by them would, with a steam pressure of 5 atmospheres and 50 HP. effective, not consume more than 4·4 lbs. of Waldenberg coal per hour per HP.

The engine was horizontal, with a single cylinder not steam-jacketed, and of the following dimensions:—

Diameter of cylinder . . . . 18·11 inches.
Length of stroke . . . . 39·37 „ with the crank axle making ordinarily 50 revolutions per minute.

The steam was led through a feed pipe, 82 feet in length, from a boiler of the following dimensions and capacity:—

Length of boiler.	25 feet.
Diameter „	31·5 inches.
Total heating surface	452 square feet.
Area of fire grate	18·9 „
Pressure authorized.	5½ atmospheres.

The fuel was good Waldenberg coal, yielding 6 per cent. of ash. Two indicators were always in use, one at each end of the cylinder, so that diagrams were taken simultaneously on both sides of the piston, and the instruments were from time to time changed about to check their accuracy. The number of revolutions were computed by a speed-indicator, and occasionally checked by counting the revolutions of the engine. The consumption of fuel was controlled by actual measurement, and the ash indicated perfect combustion. The steam gauge was checked by a manometer.

Two trials were made, in both of which the steam was so cut off that in the first about 65 indicated HP. was obtained, and in the second nearly the maximum effect. Diagrams were taken every fifteen minutes, and used to obtain a mean value.

During the first trial a pressure of only 1·818 atmosphere was reached; while in the second a pressure of 2·156 atmospheres was maintained. Taking the area of the piston, after deducting the rod, as 1,634 square centimètres (253·3 square inches), the indicated HP. is

$$N i = 0{\cdot}726\, n p.$$

n = number of revolutions, p = mean pressure in atmospheres.

The first trial gave then

$$N i = 0{\cdot}726 \,.\, 49 \,.\, 1{\cdot}818 = 64{\cdot}57;$$

and the consumption of coal being 244·4 lbs. per hour, that per HP. per hour was 3·78 lbs.

The second trial gave more favourable results.

$$N i = 0{\cdot}726 \,.\, 49 \,.\, 2{\cdot}156 = 76{\cdot}70,$$

with a consumption of fuel of 247·5 lbs. per hour, or a consumption per hour per HP. of 3·22 lbs. From this result the proportion of heating surface is only as 5·92 square feet to every indicated HP.

To obtain by calculation, approximately, the effective HP., the friction must be taken at 10 per cent. of the effective pressure, and the first trial gives

$$N e = \frac{64{\cdot}67 - 6{\cdot}15}{1{\cdot}1} = 53{\cdot}2;$$

the second trial, $$N e = \frac{76{\cdot}70 - 6{\cdot}15}{1{\cdot}1} = 64{\cdot}1;$$

so that the engine worked with an effective power of about 84 per cent.

It must be remarked that the steam was cut off to give a mean pressure of 2·5 atmospheres; hence, with 50 revolutions,

$$N i = 0{\cdot}726 \,.\, 50 \,.\, 2{\cdot}5 = 90{\cdot}75,$$

and N *e* results in about 75 HP.

The engine had been some months at work at the mills, turning out 255·8 cwts. of flour in twenty-four hours, at a consumption of 44 lbs. for every 220 lbs. of grain, and its every-day performance agreed exactly with the result of the trials.

W. E. T.

Improvement on Watt's Indicator. By M. Mallet.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 1331.)

In measurements with the indicator on machines of high velocity and very variable work, as in locomotives, where the removal of the diagrams is laborious, it is proposed to use a continuous band of paper drawn by clockwork, which can be started at will by electric contact, rendering the diagram independent of variation in the speed of the paper. A fixed tracer marks the line of atmospheric pressure, while small contacts in an electric circuit, completed by the piston-head, mark the strokes, the intervals of time being recorded if required by electric contacts established by a small clockwork movement.

P. H.

On a new Water-Pressure Pumping Engine at Clausthal. By C. R. Bornemann.

(Berg- und hüttenmännische Zeitung, vol. xxxv., p. 181.)

The completion of the Ernst August deep adit level at Clausthal having relieved the older mines of a large amount of water that was formerly pumped up and discharged through the shallower adit known as George III.'s deep level, the water power thus rendered disposable has been utilised in the establishment of a central deep pumping station for the whole district in the new Queen Mary shafts, where a quantity of 770 gallons of water may be lifted per minute to a height of 754 feet. The fall of water available as a pressure column is 1,207 feet; but in order to avoid the necessity of heavy reciprocating rods, the engines, designed by Bergrath Jordan, of Clausthal, in imitation of the newer kind of direct-acting steam pumping engines used in collieries, have been placed at the bottom of the shaft, 1,958 feet below the top of the

pressure column, and 751 feet below the deep adit through which the water is discharged. The construction of the engines is similar to that of a direct-acting steam-pump, there being two double-acting pressure pistons, each having a double-acting plunger pump placed behind it, the opposite ends of the piston rods being connected with a fly-wheel, which carries the valve gear for the engines. This consists of a pair of eccentrics, moving piston valves, which, in order to prevent shocks in the tubes at the change of stroke, are made somewhat shorter than the admission and discharge ports, so that when in mid-stroke the waterways are not completely closed. The main pressure cylinders, with their pistons and rods, are of gun-metal, as well as the valve pistons, which work in a tube lined with the same metal. Both engine and pump pistons are without packing, being turned to fit accurately in their working barrels, and are provided with annular grooves to prevent the passage of fluid from one side to the other (Ramsbottom's construction). The pistons of the pressure engines are 12·2 inches in diameter, those of the pumps 12·9 inches, the length of stroke, common to both, being 24·6 inches. The piston rod, which is carried through both cylinder covers, is 6·5 inches thick. The effective volume of the cylinder, from these dimensions, requires a consumption of 14·5 gallons of water per revolution, apart from that expended by the valve cylinder, while the corresponding discharge of the pumps is 17·2 gallons, so that the effective duty of the engines appears to be about 66 per cent. of the power developed by the pressure column. With a piston velocity of 19·7 inches per second, about fifty revolutions are made and 830 gallons of water are lifted per minute. The pumps have short suction pipes and double beat valves, whose seats are one-fourth of the sectional area of the pistons, after allowing for the section of the rods. The power water, after doing its work in the engines, is discharged with that lifted by the pumps through a common rising pipe. At this speed the velocity of the water in the driving column and rising pipe is about 3·28 feet per second; the former has to resist a pressure at the lower end of 60 atmospheres, and the latter of 23 atmospheres. The Author points out that although a plunger lift of 754 feet is very different from anything used in his own district (Freiberg),[1] a single lift of the same height was adopted in Juncker's water-pressure engine at Huelgoat, and that the engine at Illsang,[2] forcing brine to a height of ?84 feet, with one pump, worked for nearly forty years without stopping. He concludes with the expression of a doubt as to whether the disadvantage of using rotatory water-pressure engines under such a heavy backwater pressure may not more than counterbalance the advantages derived from the abolition of pump rods in the shaft.

H. B.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1843), p. 143.
[2] *Ibid.*, vol. ii. (1842), p. 55.

On a Direct-acting Pumping Engine of 500 *HP. at Rossitz, in Moravia.* By J. ILLECK, Vienna.

(Civilingenieur, vol. xxii., p. 162.)

The new deep sinking of the Rossitz Mining Company has been undertaken for the purpose of winning a large area of coal at a considerable depth, the first coal seam being reached at 931 feet, by a cross cut of the same length, which it is expected will lay open about 1,000,000 tons of coal; ultimately it is intended to sink the shaft to the depth of 1,243 feet. The geological conditions of the ground, as well as the methods adopted in sinking by means of compressed air and electric blasting, have already been described by H. von Rittler, in the Zeitschrift des berg- und hüttenmännischen Vereins für Kärnthen, 1874.

The section of the new shaft, which is laid out for drawing about 250 tons per diem (75,000 tons per annum), measures 13 feet by 15 feet 4 inches, a form that was adopted on the ground of economy. It is divided, by walls crossing at right angles, into four compartments, two of which are reserved for drawing, a third for a footway, and the fourth for the pumps and pit-work. The latter division measures 4·95 feet by 6·56 feet, being just sufficient for the pumps, although the Author considers it might with advantage have been somewhat increased in size.

The quantity of water required to be lifted from the greatest depth, 1,243 feet, is expected to be 833·8 gallons per minute, and as in the design of the engine economy seems to have been principally considered, the ordinary Cornish engine working with a considerable amount of expansion was deemed inadmissible. The use of a double-acting engine placed underground was not possible, owing to the want of a sufficiently powerful sinking engine. The shaft was actually sunk to the depth of 659 feet by the help of a small horizontal water-pressure engine. The plan ultimately selected was that of a direct-acting inverted-cylinder vertical engine working with full pressure steam through the greater part of the stroke, and non-condensing, which has been carried out by Herr G. Sigl, of Vienna, who has also supplied the 150-HP. winding engines.

The Author gives full details of the design and construction of the engine, including computations of the effective duty, but these are mainly theoretical, as only the two upper lifts of pumps have been fixed. The following are some of the principal dimensions:— The steam cylinder is 7 feet 3 inches in diameter, and weighs 336 cwt., the piston making a maximum stroke of 12 feet 5 inches. It was cast in two pieces, flanged and bolted together, the joint having been carefully gone over in the boring lathe, after the two halves had been first bored separately. The foundation plate, weighing 180 cwt., which is at the same time the lower cylinder cover, and contains the steam ports, is strengthened with six vertical ribs in

order to prevent it springing under the great and constantly varying pressure of steam, amounting at a maximum to 153½ tons, a phenomenon which is not uncommonly observed in engines of this class when sufficient stiffness has not been given to the bottom casting. The top cylinder cover, having no great strain to resist, is considerably thinner. It has a port for communication with the exhaust steam, and a man-hole for examining the piston. The cylinder is not jacketed, but coated with Lervi's composition, and painted.

The piston is of ordinary construction, having two metal packing rings, with eight steel pressure springs. The connection with the piston rod is so contrived that it may be more easily removed for examination or repair than is possible with the ordinary arrangement of wedges or screws. The weight of the complete piston is 92 cwt.

The piston rod, of Bessemer steel, forged in one piece, is 22 feet long, 9·3 inches thick, and weighs 46 cwt. It is connected at the upper end with the piston by a carefully-finished conical boss, and at the bottom with the cross head of the main rod in the shaft by a screw thread, which reduces the effective section to 8·3 inches. The steam valves are of the ordinary double-beat Cornish construction, with cataract and tappet gear, worked by an auxiliary beam, making a stroke of 48·7 inches, or one-third of that of the main rod. The admission valve is 5·5 inches in diameter, with a lift of 1·96 inch, and the exhaust is 12·4 inches in diameter, with a lift of 1·57 inch. The bearing faces are 0·21 inch wide. The former opens upwards and the latter downwards, an arrangement which, by allowing the spindles of both to be directed upwards and moved from above, adds somewhat to the symmetry of the tappet gear. Steam is admitted through a vertical tube of 18·7 inches diameter on the right-hand side of the engine; a similar tube on the left side forms a communication with the top of the cylinder. The exhaust takes place through an elbow at the bottom of the latter tube by an underground passage, where it is in great part condensed, so that the usual monotonous song of this class of engine is prevented. The top steam passage is for protecting the cylinder from loss of heat when the engine is working slowly. The valve-boxes, casing tubes, &c., together weigh 232 cwt. The construction of the valve gear differs somewhat from that of an ordinary Cornish engine, all quadrant catches and weights being dispensed with, as the valves are closed directly by the tappet rod and opened by the cataracts; the latter movement being effected gradually, instead of the valve being suddenly opened by falling weights, in which case the work of the cataract is confined to unlocking the weights. Both cataracts are of the same dimensions, having pistons 8·26 inches in diameter and stroke. The discharge valve is 1·57 inch and the admission 2·56 inches in diameter. In order to secure regularity of working in frosty weather, the cataracts are filled with glycerine instead of water.

The wrought-iron main rod, of hollow rectangular section,

formed by two flat plates and two] irons, is divided into sections of varying dimensions, according to the position of the pumps, there being four plungers and a bottom drawing lift. The sections between the first and second lifts, and also that between the third and fourth, are diminished by reducing the substance of the iron, the external dimensions remaining unchanged, while in that between the second and third lifts both the size of the rod and the thickness of the plates are diminished. The rod is put together in lengths of 30·6 feet, which are united by long fish plates, secured by one hundred and twelve conical steel bolts, giving a greater strength at the butts of the rod plates than that of the complete section of the rod. In each length of the rod a portion 16·5 feet long is packed with oak and moves between guides of the same material attached to the timbers in the shaft, the distance between the guides being 30·6 feet. The upper section of the rod to the first lift is made up of two flat side plates 12·44 inches by 0·71 inch, and two ⊔ irons of 11·81 inch by 3·34 inch by 0·71 inch section, riveted together; the rivets are 0·079 inch in diameter, and the pitch is 8·26 inch.

At the points of attachment of the plungers, which are placed symmetrically in the central line of effort, the rod is divided into two, each side being formed of two ⊔ irons, placed back to back, with a narrow covering plate overlapping the flanges. The total weight of the rod, when completed to the full depth of the shaft, will be about 125 tons. The Author points out that the form of the rod is mechanically imperfect, it being three and a half times as strong as a solid rod of the same section, but only one-third of the strength of a box section of equal substance. It would have been necessary, therefore, in order to obtain a stiffer rod, to use four flat plates and angle irons, a construction which would not have given facilities for the proper attachment of the pump plungers, for which purpose the ⊔ iron is admirably suited.

The cylinder and its foot-plate are carried upon two heavy wrought-iron girders of II section, weighing about 11 tons each, 27·8 feet long and 4·8 feet high, having a bearing at each end of 6·2 feet, upon massive stone abutments. The load upon these at the commencement of the stroke is about 215 tons, which is not borne centrally, but considerably to one side, and corresponds to a strain of 1·27 ton per square inch of section. The length of stroke is determined by stops on the rod, which are received against a catch-block, consisting of twenty-nine balks of oak, united into a solid mass, let into the walling of the shaft at one end, and received at the other between wrought-iron girders, carried into the brattice wall between the pumping and winding divisions. The Author points out that this catch-piece, in spite of its enormous mass, would be perfectly inefficient in the event of a sudden fracture of the rod, as it would then be required to resist half the unbalanced weight falling through a height equal to the stroke of the engine, or a momentum of 448,700 foot-lbs., whereas its actual resistance would be overcome by 30,100 foot-lbs. The

safety of the machinery therefore is only to be looked for in careful attention to the valves, and the avoidance of shocks as much as possible. The plunger lifts are placed at intervals of 280 feet apart, between the suction valves. The drawing lift is to be 107·6 feet below the lowest plunger.

The mean velocity of the water per second in the rising pipe is 24·8 inches, as compared with 15·7 inches in the great 39-inch pumps of Bleiberg, in Belgium, which latter speed is considered to be unnecessarily low, as increasing the cost of the engines without any corresponding advantage.

The water raised at each stroke of the plunger, instead of being discharged into the cistern immediately at the level of the suction valve of the next lift above, is received into a so-called compensating pipe. This is a continuation of the rising pipe, with a diameter reduced from 18·66 inches to 9·84 inches, whereby the contents of the plunger barrel are lifted 62·3 feet above the foot valve of the next lift, thereby absorbing a considerable amount of the work of the excess weight of the rod near the end of the stroke. This is utilised on the return stroke, being brought to bear directly upon the suction valve of the upper lift, which is thus subjected to an extra pressure of about 2 atmospheres from the feed column. There being at present only two plunger lifts, as the discharge of the upper one takes place at the surface, the lower one is fitted with the compensating tube; the effect in equalising the work is said to be very apparent, even although it is distributed over two lifts. The engine is worked with a length of stroke of only 5 feet 8½ inches, leaving a space of 6 feet 6 inches, which is filled with water condensed from steam above the piston, or a weight of 17·2 lbs.

The following table gives the weight of the entire arrangement:—

	Tons	cwt.
The engine, exclusive of foundations	58	0
Five foundation girders, &c.	39	3
Four plunger lifts	116	16
Drawing lift	15	18
One wrought-iron main rod and spare pieces	95	15
Wrought-iron rising pipe, 984 feet long	39	10
Three cast-iron compensation tubes, 187 feet long	9	0
The winding engine	26	3
Total weight of machinery	400	5

The duty of the engine and pumps, when completely finished, is estimated at 64 per cent., or 2,364,250 foot-lbs. per stroke, which at five strokes per minute is equal to 363 effective, or 562 gross HP.

H. B.

The Construction of Gasholders.[1] By M. Arson.

(Mémoires de la Société des Ingénieurs Civils, 1875, p. 630.)

The gasholder, from its great relative cost and the difficulties besetting its construction, always deserves study. The capacity being fixed by the necessities of the case, the height varies inversely with the area at command. In good soils the holder may be of the single form, up to 41 feet in height; but where deep excavation is inexpedient, the telescope form may be adopted.

Useful as was the existing experience, the Parisian company hesitated to sink so much capital as is involved in such works without first solving in precise terms the necessary proportions of the masonry, the guide framing, the hydraulic cup, &c. The following are the results of their investigations:—

Earthworks.

When the soil is solid and can be excavated in a true form, the masonry can be raised and butted against it; but when the soil is loose and unstable, the masonry must be surrounded with a compact and dense filling-in, preferably of sand watered and rammed in thin layers. This latter course was adopted with a tank at Ternes, where the wall was 4 feet 3 inches thick, and had 42 feet head of water pressure against it. Sand so treated was known to form a good foundation under vertical pressure. It was tested for resistance to horizontal pressure, and compared with other earths, by an hydraulic machine bearing on 10·76 square feet of surface, and further by a lever or steelyard machine, bearing on 5½ square inches. Ramming in layers 4·75 inches thick for sand, and 2 inches thick for other earths, gave the best results. Earthy impure sand increased in density when rammed in thinner layers; the weight of 117·8 lbs. per cubic foot increasing to 120·3 lbs. River sand, however, gave no higher weight than 111·6 lbs. per cubic foot under the same treatment. River sand in its natural state weighs 93 lbs. per cubic foot, which can be increased by ramming to 111·6 lbs. Mould can be increased from 74·4 lbs. to 111·6 lbs. This alone shows the superiority of sand. In a series of tests of compressibility, the white clay of Paris gave 80 per cent., and mould only 44 per cent. of the resistance of sand.

Masonry.

In considering the masonry of tank walls, its weight and cohesion are the sources of resistance to the internal water pressure. Of available materials, bricks rank first, limestone second, and millstone last. For mortar, either hydraulic lime or Portland cement may be used.

---

[1] The basis of this communication was a pamphlet published by the Parisian Gas Lighting and Heating Company, on the occasion of the Vienna Exhibition.

The importance of building the wall solidly against the excavated profile of natural earth—or, when a filling-in has to take place, of carrying it out compactly—is dwelt upon at length. From the fact of tank walls splitting vertically near the top, with a fissure narrowing downwards, it is deduced that the resistance behind the masonry was not in such cases sufficient to prevent deformation and displacement.

The condition of absolute equilibrium between the pressure of water on the one hand, and the resistance of the masonry, by its weight and cohesion aided by the pressure of surrounding earth, on the other, is expressed in the following equation:—

$$1000 \text{ kilogrammes } (0 \cdot 984 \text{ ton}) \frac{H^3 D}{6} = \frac{C D' H^2}{2} + \frac{P E^2 D' H}{2} + K H^2 E$$

wherein H is the depth of the tank, D and D′ the internal and external diameters, E the thickness of the masonry, and C, P, and K represent the respective constants for the resistance of earth, the weight of masonry, and the cohesion of masonry.

Applying the above formula to the tank at La Villette, where the dimensions were, $H = 41 \cdot 65$ feet; $D = 183 \cdot 7$ feet; $D' = 192 \cdot 75$ feet; $E = 4 \cdot 527$ feet: the constants, $C = 0 \cdot 278$ ton; $K = 4 \cdot 178$ tons, and $P = 0 \cdot 018$ ton: the pressure of water, 18,731 tons, is opposed by

Pressure of Earth.		Weight of Wall.		Cohesion of Wall.		
46,638 tons	+	1,528 tons	+	32,936 tons	=	81,102 tons.

Cements and Mortar.[1]

The watertightness of the tank depends absolutely on the rendering of the internal face with cement plaster. A tank at La Villette was plastered with a mixture of equal parts of Vassy cement and sand. The Portland cement of Pouilly is instanced as containing 61 per cent. of lime, 32 of silicate of alumina, and 5 per cent. of oxide of iron. The cement of Vassy consists of 68 per cent. of lime, and 32 per cent. of silicate of alumina, and weighs 62·42 lbs. per cubic foot.

Cement is better, and sets more slowly, with the least free lime. It weighs from 83·7 lbs. to 96·1 lbs. per cubic foot. It is heavier as the burning is carried to higher temperatures. The strength of it is so far improved by time after setting, that a similar briquette to one which broke at a strain of 3·75 cwt. in six weeks, broke at 9·9 cwt. in eight months.

[1] *Vide* "Experiments on the Strength of Cement, chiefly in reference to the Portland Cement used in the Southern Main Drainage Works," by J. Grant, Minutes of Proceedings Inst. C.E., vol. xxv., p. 66; and "Further Experiments on the Strength of Portland Cement," by J. Grant, Minutes of Proceedings Inst. C.E., vol. xxxii., p. 266. Also "Experiments on the Portland Cement used in the Portsmouth Dockyard Extension Works," by C. Colson, Minutes of Proceedings Inst. C.E., vol. xli., p. 125.

For rendering, 3 parts of sand to 1 part of cement are mixed with an excess of water, and allowed to drain to a pasty condition, which takes place in from one to four hours.

A series of tests were made with cements for impermeability to water under pressure, and for cohesive strength with the following results:

Cements of all kinds set better in water or wet sand for both purposes, but the permeability of cement set in air decreased after the test had forced water into its pores. Age after setting improved the impermeability as well as the cohesion; floating the surface smooth improved the impermeability.

The addition of sand up to equal parts improved the strength; beyond that proportion its effect was to cause progressive weakness. In constructing tanks the floors are paved and rendered with plaster like the walls, great care being necessary round the guide attachments and the landing stones to avoid leaks. The plastering varies from 1·18 inch to 3·15 inches thick.

Gasholders.

The gasholder is a cylinder closed at the top by a segment of a sphere or dome, so shaped as to pass off rain-water and to lessen the strain on the attachment to the cylinder at the curb. The great strain at this point necessitates the plates at the outer edge of the dome and at the top of the cylinder being heavier than the rest. The lowest row of plates in the cylinder is also heavier, and is moreover stiffened with a curb, to prevent deformation.

In the holder at La Villette a box girder, 6·56 feet wide and 3·28 feet deep, of plates 0·276 inch thick is so applied. Guide rollers to be rigid should be fixed on the cylinder, not on the dome.

For carriages and attachments cast iron, being brittle, should be avoided; bolts and nuts are inferior to rivets. Wrought-iron plates and angle iron are better materials. The axles of the rollers are recommended to be shaped eccentric in the ends which bear in the carriage, so as to be capable of advancing or receding the roller by a partial revolution.

The importance of adequate strength of section in the top curb or angle iron joining the dome top with the cylinder, as well as of a considerable angle at this part, is insisted upon. The strains are deduced as follows:—

1st. The strain upon the top sheet at the curb

$$= \frac{\text{weight of the cylinder (disregarding the top)}}{\text{circumference} \times \text{sine of the angle at the curb.}}$$

2nd. The tensile strain on the rivets

$$= \frac{\text{weight of the cylinder}}{\text{circumference}} \times \text{cosine of the angle at the curb.}$$

3rd. The distorting strain on the curb

$$= \frac{\text{weight of cylinder}}{\text{circumference} \times \text{tang. of the angle at the curb.}}$$

Telescopic Gasholders.

In telescope holders the hydraulic cup should have a depth sufficient, 1st, to secure a seal against the pressure of the gas; 2ndly, to cover a possible tilting of the upper lift in coming into action; and lastly, to contain enough water to guard against loss by leakage and evaporation while in action.

It is recommended that the lower lift be shorter than the upper, so as to plunge the grip underneath the water in the tank, with the view of securing a cupping when the water-level is low, to protect it from frost, and to allow the rollers on the upper lift to be fixed to the side of it rather than to the top as already advised. Tanks of ordinary form are preferred to annular ones, as the larger bulk of water is less liable to freeze. To protect the water in the hydraulic cup from freezing, a steam chamber in the side is recommended.

The construction of the wrought-iron work is fully described. The plates are interchangeable, all sheared and punched to templates, and then flattened. Soft Swedish iron is preferred for rivets, all of which should be driven cold. The angle irons are curved and bevelled as required by rollers grooved to the various sections and angles. In construction the sheets are temporarily bolted together for at least three rows before riveting, to give play for adjustment. No paint or other substance is introduced in the laps, oxidation of the metal being relied on to prevent leakage. Pending the construction the sheets have to be stayed and supported by timber.

Inlet and Outlet Pipes.

These should be of ample section, as the speed of the current of gas during emission should not be higher than 16 feet per second, and as they are liable to be partly choked with crystals of naphthaline. In view of this last event they should be contrived so as to be readily cleaned out. They should be arranged on an interchangeable system, that one may be substituted for another when necessary.

Wrought-iron pipes, hinged with stuffing boxes and in three sections, rising and falling with the holder, are recommended in preference to the inverted siphon pipes, as they are claimed to be cheaper, to work satisfactorily, and to be always free from naphthaline.

Guide Framing.

The stability of the holder has to be secured against, 1st, any tilting or lurching of the holder itself out of the perpendicular; 2ndly, the influence of side winds; 3rdly, the possibility of obstruction in the ascent or descent at one point of the circumference. Of these the wind is considered the most important, as within the

limits of the strength of the holder itself the other influences, which are abnormal, could give no higher strain. A full analysis of cases where four, six, eight, or more columns are applied to single holders, and twenty columns to a telescope holder, follows, based on the use of wrought-iron cylinders for columns, lattice girders for stays, and the use of tangential guide rollers. The highest wind pressure is taken at 57 lbs. per square foot of plane surface, and the reduction of its power over a cylindrical body as compared with a prism is deduced from experiments with currents of water to be 54 per cent. The net equivalent upon a holder is taken at 26·22 lbs. per square foot of cross section. With tangential rollers one-fourth of the whole of this pressure is exerted against the top of each of the two guide columns at right angles with the direction of the wind, and in the ordinary case of overthrow by deformation of the members of the structure all the columns, whatever their number, must be simultaneously torn down, as being tied and stayed horizontally, they come equally into play for resistance.

Thus for *n* number of columns, one half the entire side pressure is opposed by *n* times the resistance of each column. For the horizontal stays to columns it is attempted to be shown that if the first tier is at the middle height of the columns, it should be twice the sectional area of the second tier. The vertical and horizontal strains upon each girder are deduced in terms of the wind pressure.

The formula of resistance of both columns and girders are applied to the case of a gasholder at La Villette.

Scaffolding.

For the support of the gasholder crown when landed a wooden scaffold is recommended, adapted to serve also for the construction of the whole work, both cylinder and crown.

To distribute the weight over the entire area of the bottom of the tank, this scaffolding involves a large number of equidistant upright posts arranged concentrically in circles. Their heads are fitted with wooden ties and cross bearers, fixed by preference after the cylindrical portion of the holder is completed, and adjustable to the exact height and shape that may be necessary.

H. E. J.

On the Evaporation of Superheated Liquids.

By D. Gernez.

(Annales de Chimie et de Physique, 5th series, vol. viii., p. 113.)

In a preceding memoir (Annales, 5th series, vol. iv., p. 335) the Author has collated the experimental proofs which establish that evaporation is the only normal mode of vaporisation of liquids, and in the present memoir the evaporation of liquids at tempera-

tures above the boiling point is studied. For all liquids experimented with it has been found that there is a rate of evaporation which remains constant at every temperature, whatever may be the surrounding temperature, and the rate of evaporation is sensibly independent of the nature of the medium into which the vapour is disengaged. The duration of evaporation of a column of liquid of determined height, measured when disengaged freely into the atmosphere, and when ignited at the extremity of a tube, proved this; a column of carbon bisulphide, 50 millimètres in height, heated to 90°, discharged itself into the atmosphere in 2 minutes 26 seconds, and in 2 minutes 27 seconds when the vapour was ignited at the end of a tube. In the same tube, containing the same quantity of liquid heated to 100°, the period of evaporation was 1 minute 46 seconds, whether the vapour was ignited or not. The rapidity of evaporation is inversely as the diameter of the tubes in which the evaporation is conducted, as the following numbers have shown:—

	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Diameters	15	5	3	2	1	0·35	0·2
Rate of evaporation .	1	2·2	2·7	3·6	10	21·90	30·0

If curves are constructed having for abscissæ temperatures reckoned from the normal point of ebullition, and for ordinates the periods of evaporation of the same height of liquid corrected for expansion, the series of curves have for asymptote the time-axis, and the convexity is towards the temperature-axis. The series corresponding to capillary tubes of 0·6 to 0·32 millimètre diameter differ little from hyperbolas related to rectangular asymptotes.

P. H.

On the Expansion of a Gas without Variation of Heat, and without External Work. By J. Moutier.

(Annales de Chimie et de Physique, vol. vii., p. 318.)

When a gas expands without receiving or emitting heat, two cases are to be distinguished, according as the gas performs external work or not. The second case is here considered; it has been studied by Hirn, whose law on the subject is enunciated as follows:—When a vapour expands without variation of heat, and without performing external work, the product of the volume of the vapour and the pressure is constant. Hirn and Zeuner, it is stated, consider this law an approximation.

The Author applies to the question under consideration the general formulæ of thermo-dynamics, forming three distinct problems, according to the pressure, the specific volume, or the temperature, which are considered as independent variables.

In the first case the volume (v) and the pressure (p) are the

independent variables. C is the specific heat at constant pressure, and c at constant volume; θ and θ' are the given temperatures added to the reciprocals of the expansion under constant pressure and constant volume, and the co-efficients λ and K in the following equation have the known values:

$$\lambda = \frac{C\,\theta}{v} \text{ and } K = \frac{c\,\theta'}{p} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

then $$d\,Q = \lambda\,dv + K\,dp \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

represents the quantity of heat necessary to produce an elementary variation in the volume dv, and in the pressure dp. But

$$d\,Q = A\,p\,dv + d\,U \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2a)$$

in which A is the calorific equivalent of work (the reciprocal of Joule's equivalent), and d U the increase in internal heat.

Equating these two values,

$$d\,U = (C\,\theta - A\,pv)\frac{dv}{v} + c\,\theta'\frac{dp}{p} = 0. \quad . \quad . \quad (2)$$

for in the expansion here considered $d\,U = 0$, as heat is neither received nor emitted; or otherwise

$$\frac{C\,\theta - A\,pv}{c\,\theta'}\frac{dv}{v} + \frac{dp}{p} = 0;$$

putting $\dfrac{C\,\theta - A\,pv}{c\,\theta'} = n$, and supposing n constant, at least within certain limits,

$$n\,\frac{dv}{v} + \frac{dp}{p} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

gives as its immediate integral

$$pv^n = \text{constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

the law of the expansion of gas under the stated conditions. This is the equation of Cazin's isodynamic curve.

For the permanent gases n is sensibly constant, θ and θ' differ slightly, since the expansion at constant pressure and constant volume are nearly similar, and differ but little from the absolute temperature T, and c and C are sensibly constant. For vapours generally n has a particular value for each state of the gas, and can be determined from the two specific heats, the two co-efficients of expansion, and the volume. All of these are known from Regnault's experiments, except the specific heat at constant volume.

But $$C = c + A\,T\frac{dp}{dt} \cdot \frac{dv}{dt};$$

and since

$$\frac{dv}{dt} = \frac{v}{\theta} \text{ and } \frac{dp}{dt} = \frac{p}{\theta'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\beta)$$

$$C = c + A\,pv \frac{T}{\theta, \theta'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

from which, substituting the value of $A\,pv$,

$$n = \frac{C}{c}\left(\frac{1}{\theta'} - \frac{1}{T}\right)\theta + \frac{\theta}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and it is evident from inspection that n is nearly unity in permanent gases. Hirn's law, it is stated, supposes $n = 1$ in all gases and vapours, and it is further considered that for vapours the law may be considered sufficiently approximate for the study of machines.

When a gas expands with the performance of external work

$$pv^m = \text{constant},$$

in which

$$m = \frac{C\,\theta}{c\,\theta'};$$

and hence $n = m - \frac{C - c}{c} \frac{\theta}{T}$, or is always less than m.

It is easy to compare the variation of pressure with volume in the two cases of the non-performance and performance of external work. From the equations already given

$$np\,dv + v\,dp = 0;$$
$$mp\,dv + v\,d'p = 0;$$

$d'p$ being the variation of pressure with the performance of external work. Hence

$$\frac{dp}{d'p} = \frac{n}{m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

or the variations of pressure are proportional to the co-efficients of expansion.

In the second case the specific volume v and the temperature t are the independent variables. In the following equation, according to Carnot's theorem, and substituting (β)

$$l = A\,T\frac{dp}{dt} = A\,p\frac{T}{\theta'};$$

then

$$d\,Q = l\,dv + c\,dt;$$

equating with the value (2), and $d\,U$ being $= 0$ in this as in the preceding case,

$$A\,p\frac{T - \theta'}{\theta'}\,dv + c\,dt = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

This law is analogous to that of a gas performing external work without variation of heat.

From the above law it follows that dt is negative if θ' is inferior to T. If a is the co-efficient of expansion of a perfect gas, and a' has the value already given, then a' is greater than a; that is, a gas cools in expanding without variation of heat, and without performing external work, when the co-efficient of expansion of the gas under constant volume is superior to that of perfect gases.

From the preceding value of n when θ' is inferior to T the co-efficient n is superior to $\frac{\theta}{T}$, or the co-efficient of expansion under constant pressure is superior to that of perfect gases; and as n is greater than or equal to unity, a gas which follows the law of Hirn necessarily cools on expansion without variation of heat, and without external work.

The minimum value of $n > \frac{\theta}{\theta'}$ also follows from the above relation.

Hirn has found that superheated steam at 200° follows sensibly Mariotte's law at atmospheric pressure, hence it is deduced that it cannot follow Hirn's law, viz., $n > 1$.

The method of obtaining a value of n from know data is then given, and this quantity is found equal to 1·015 at the last stated temperature and pressure, a number nearly equal to unity.

The variation of temperature with and without the performance of external work is nearly zero in permanent gases, and is the equivalent of the external and internal work when both are performed, and of the latter alone when it only is performed.

The third case, where p and t are the independent variables, is deduced from the other two (3a and 7), and the algebraical statement of the law is

$$- A v \frac{T - \theta'}{n \theta'} dp + c\, dt = 0 \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The Author then considers the following consequences relative to the theory of gases:—

1. The variation of the internal heat in a gas submitted to the law of Hirn.

In this case $n = 1$, and equation (2) assumes a remarkable value:

$$C\theta - Apv = c\theta';$$

$$dU = \frac{c\theta'}{pv} d(pv).$$

Here the variation of internal heat is proportional to the increase of pv; and reciprocally, if this is the case, the gas follows the law of Hirn.

Suppose that the variation of internal heat can be expressed by

$$dU = \mu\, d(pv) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

where μ is constant. Then $d\,U$ in the assumed case is zero, and $pv =$ constant, which is Hirn's law.

It is then shown that the above condition would be satisfied for every elementary transformation the gas undergoes, if it is satisfied for any two arbitrarily assumed transformations.

It is easy to verify this interpretation of Hirn's law.

$$\begin{aligned} C\,dt &= A\,p\,dv + \mu\,p\,dv \\ c\,dt &= \mu\,v\,dp, \text{ or otherwise} \\ C\,\theta &= (A + \mu)\,pv \text{ and } c\,\theta' = \mu\,pv \end{aligned}$$

hence $$C\,\theta - A\,pv = c\,\theta',$$

and from the previous value of n it follows that $n = 1$.

Dividing both sides of this equation by $c\,\theta'$, and substituting the values of m and μ, it follows that

$$\mu = \frac{A}{m - 1},$$

and that μ therefore depends upon m.

2. Internal work in gases.

From the original experiment of Gay-Lussac, afterwards more carefully made by Joule and Regnault, the internal work is generally admitted to be nil. But it has here been found, from an application of the laws of thermo-dynamics, that a variation dv produces a variation dt, given by (7). In order that there may be no internal work, dt must be nil, or that, contrary to the experiments of Regnault, the co-efficient of dilation under constant volume must be constant. Hence there is internal work in all known cases, which is very small in permanent gases, but can be absolutely nothing for only one gas.

3. Molecular forces in gases have been considered as nil, but from Clausius's view

$$h = V + \tfrac{3}{2}\,pv,$$

in which h is the *vis viva* of the motion constituting the heat, and proportional to the absolute temperature; V is the interior virial, or the half sum of the product of the distance of two points by the force which acts between them. Clausius has shown that $\frac{3}{2}\,pv = 0\cdot615\,h$ in permanent gases, so that the molecular forces cannot be neglected.

4. Determination of absolute temperature and the mechanical equivalent of heat.

In determining the mechanical equivalent by the method of Mayer, the heat consumed in internal work is neglected, and the values arrived at agree for the permanent gases, but are too low for those which can be liquefied, because evidently in the latter the internal work is greater.

Let A′ be the heat-equivalent of work by Mayer's method:

$$C = c + A' p \frac{dv}{dt}, \text{ or}$$

$$C = c + A' \frac{pv}{\theta}.$$

If A is the true equivalent from equation (4),

$$A' = A \frac{T}{\theta'},$$

and hence

$$\frac{E'}{E} = \frac{\theta'}{T}.$$

When a gas cools by expansion without variation of heat, and without the performance of external work, θ' is less than T, and E′ is less than E; the value of the mechanical equivalent of heat obtained in such a case by Mayer's method is too little.

E. B.

On the Elasticity of Air under Feeble Pressure. By E. H. Amagat.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 914.)

The Author arrives at the result that under feeble pressures (mean initial pressure 6·538 millimètres to 10·552 millimètres) air follows Mariotte's law. Several observers have remarked that in circumstances analogous to those under which the Author worked, after creating the vacuum and having closed the apparatus, the pressure sensibly increases for a long time, a phenomenon which appears to be due to the air condensed on the sides under ordinary pressure, and escaping gradually under diminished pressure. The Author had also noticed this, and attributed the effect to leakage in the apparatus until it was found that, after a sufficient time, the pressure remained perfectly stationary. The effect is therefore thought to be not so serious a cause of error as has been believed. Mendeléeff and Kirpitschoff have recently arrived at very different results, as under feeble pressures these observers have found sensible differences from Mariotte's law, and in the same direction as that of hydrogen; but the Author assumes that in elevating the temperature of hydrogen Mendeléeff and Kirpitschoff's researches would lead one to think that the gas became less and less compressible, whereas he proved, some years since, that exactly the contrary takes place.

P. H.

On the Intensity and Penetration of Light in Lighthouse Illumination.

By M. E. ALLARD, Civil Engineer-in-Chief to the French Government.

(Annales des Ponts et Chaussées, vol. xiii., p. 5.)

The subject is treated at some length: there is first considered the advantages arising from the introduction of mineral oils for the purposes of lighthouse illumination, by which, as expense of consumption has been decreased, it has been possible to add extra wicks to the lamps, thus giving a new order of lights. The present lighthouses are divided into five orders, according as their lenticular apparatus has a diameter of 1·84, 1·40, 1, 0·5, or less than 0·5 mètre. The lamps that usually correspond to these five orders have burners in which the number of concentric wicks is 5, 4, 3, 2, 1, and of which the exterior diameter is 11, 9, 7, 5, and 3 centimètres. Each wick is contained between two copper cylinders 5 millimètres apart, and is separated from the neighbouring wick by an annular space, or air-passage of 5 millimètres; the mean diameter of each wick is therefore 105, 85, 65, 45, 25 millimètres. The quantity of mineral oil consumed by each order in one hour may be taken at 55, 175, 370, 645, 1,000, 1,450 grammes. If points are laid down having these numbers (c) for ordinates, and the diameter (d) of the burners for abscissæ, a curve is formed of which the equation is

$$c = 4 \cdot 9\, d^{2 \cdot 22}.$$

The flames produced by different lamps increase in height with the diameter of the burner. Substituting for the irregular form of the flame an approximate elliptic form, it is found that the height of these different elliptic flames increases nearly proportionally to the square root of the diameter, and may be represented by the formula

$$h = 2 \cdot 73 \sqrt{d},$$

h and d being taken in centimètres. The apparent surface of each flame is $\frac{1}{4}\pi\, h\, d$, or $2 \cdot 144\ d^{\frac{3}{2}}$, and the volume of flame is expressed by $\frac{1}{6}\pi\, d^2\, h = 1 \cdot 4294\, d^{\frac{5}{2}}$. Every decagramme of oil consumed per hour maintains a volume of flame which, in the different orders, is 4·05, 4·57, 5·01, 5·39, 5·74, 6·01, to which corresponds the formula $u = 0 \cdot 2917\, d^{0 \cdot 28}$.

Taking as unit the light of a Carcel lamp burning 40 grammes of colza oil per hour, the intensities of the several mineral oil flames are $I = 2 \cdot 2, 6 \cdot 9, 14 \cdot 3, 24, 36, 50$, represented by a curve having the approximative formula $I = 0 \cdot 22\, d^{2 \cdot 1}$. If these inten-

sities are compared with the apparent surfaces and volumes, the ratios are

$$\frac{\mathrm{I}}{\mathrm{S}} = 0{\cdot}197, \quad 0{\cdot}288, \quad 0{\cdot}360, \quad 0{\cdot}415, \quad 0{\cdot}460, \quad 0{\cdot}498,$$

or intensity per square centimètre apparent surface;

$$\frac{\mathrm{I}}{\mathrm{V}} = 0{\cdot}0987, \quad 0{\cdot}0864, \quad 0{\cdot}0772, \quad 0{\cdot}0691, \quad 0{\cdot}0628, \quad 0{\cdot}0574,$$

or intensity per cube centimètre of volume; showing that the intensity increases much more rapidly than the apparent surface, but not proportionally to the volume, and that flame is not completely transparent, for, with increase of temperature and increase of specific luminous intensity, the mean intensity diminishes, whilst the volume increases. In a theoretical consideration, it is necessary to imagine a homogeneous flame, and to attribute to this a specific intensity and transparency equal to the mean values of intensity and transparency of the actual flame. Let a volume, V, of homogeneous flame be supposed, of which the specific luminous intensity per unit of volume is i, and the coefficient of transparency a number, a, smaller than 1, which represents the proportion of light passing unity of length of flame traversed. The luminous intensity of this volume of flame would be $\mathrm{V}\,i$ if transparency were absolute, or $a = 1$. It remains to determine this intensity for a known value of a. Let w be the section, and l the length of a small cylinder of flame, an element of volume $w\,d\,x$ should produce a luminous intensity $w\,i\,d\,x$, and this luminous intensity, traversing a depth x of flame, would become when issuing from the cylinder $w\,i\,a^x\,d\,x$. The luminous intensity I then is

$$\mathrm{I} = \int_0^l w\,i\,a^x dx = w\,i\,\frac{1 - a^l}{-\log a},$$

which when $l = \infty$ is

$$\mathrm{I} = \frac{w\,i}{-\log a}.$$

If a be supposed $= 0{\cdot}8$, a horizontal cylinder of flame 10 centimètres in length would give no more light in the direction of its axis than a length of 4 centimètres would give under the hypothesis of absolute transparency, and, increasing indefinitely the length of the cylinder, no further intensity would accrue than would be attained with a length, under the same hypothesis, of $4{\cdot}48$ centimètres. For $a = 0{\cdot}7$ this limit would be $2{\cdot}8$ centimètres; $1{\cdot}96$ centimètre for $a = 0{\cdot}6$, and $1{\cdot}44$ centimètre for $a = 0{\cdot}5$, rising to $9{\cdot}49$ centimètres for $a = 0{\cdot}9$. Considering, however, a flame having the form of a solid of revolution of a semi-ellipsoid, of which the axis is vertical, and is taken for the axis of z, a horizontal

prism parallel to the axis of x, having a section $d\,y\;d\,z$, and length $2\,x$, would give in the direction of the axis of x an intensity which, acccording to the preceding formula, would be

$$d\,y\,.\,d\,z\,.\,i\;\frac{a^{2x}-1}{\log.\,a},$$

and the total intensity in any horizontal direction

$$\mathrm{I} = i\int_{z=o}^{z=h} d\,z \int_{y=o}^{y=\rho} d\,y\;\frac{a^{2x}-1}{\log.\,a}$$

taking into account the two relations $y^2 + x^2 = \rho^2$, $\frac{z^2}{h^2} + \frac{\rho^2}{r^2} = 1$, in which x, y, z are the co-ordinates of a point of the surface of the ellipsoid, h the height, r the radius of base, and ρ the radius of the horizontal circle at the height z. Dividing this effective intensity I by the absolute intensity $\mathrm{V}\,i$, there results the co-efficient of reduction k, which it is necessary to calculate. This the Author effects by considering that the co-efficient is the same for a sphere as for an ellipsoid; and dividing the volume of the sphere by a series of parallel cylindrical surfaces, having for axis the axis of x, the volume comprised between two of these surfaces is $2\,x \times 2\,\pi\,y\,d\,y$, and its luminous intensity in the direction of x would be

$$i\,2\,\pi\,y\,d\,y\,\frac{a^{2x}-1}{\log.\,a}.$$

Between the limits $y = o$ and $y = r$, dividing by the volume of the sphere, and taking into account the relation $x^2 + y^2 = r^2$, putting $y\,d\,y = -\,x\,d\,x$, the integral is

$$\int_{x=r}^{x=o} x\,d\,x\;(1 - a^2\,x) = \left[\frac{x^2}{2} - \frac{xa^{2x}}{2\log.\,a} + \frac{a^{2x}}{4\log.\,^2a}\right]_r^o$$

$$= -\frac{r^2}{2} + \frac{r\,a^{2r}}{2\log.\,a} - \frac{a^{2r}}{4\log.\,^2a} + \frac{1}{4\log.\,^2a};$$

whence, putting $2\,r = d$,

$$k = \frac{3\left(1 - a^d + d\,.\,a^d\log.\,a - \frac{1}{2}\,d^2\log.\,^2a\right)}{d^3\log.\,^3a}$$

So that when the co-efficient of transparency, a, is known for a flame of which the diameter of base is d, the effective intensity of this flame will be

$$\mathrm{I} = k\,.\,\mathrm{V}i.$$

The mean of a set of three trustworthy experiments with lapsm

having flat wicks (measured from the edge and width of the flame, the calculated ratio being $m = \frac{l(1 - a^e)}{e(1 - a^l)}$, where l = the width and e the depth) gave $a = 0 \cdot 72$; and some experiments made by means of catadioptric reflectors gave a mean $a = 0 \cdot 86$; whilst other trials made with the electric light traversing a flame gave $a = 0 \cdot 80$. For the six ratios of $\frac{I}{V}$ previously given, the values of a are tabulated, and it is shown that hypotheses of $a = 0 \cdot 9$ and $a = 0 \cdot 85$ are inadmissible, because they include the consequence of diminution of specific intensity of the flame as its diameter increases. That value of a which appears best to accord with experimental and theoretical results is $0 \cdot 80$.

Comparing the consumption of oil for these absolute and effective intensities, the following ratios are obtained:—The consumptions of oil per unit of absolute intensity in grammes are: 19·75, 17·27, 15·50, 14·18, 13·07, 12·24. The consumption diminishes rapidly with increase in the diameter of the burner; with a five-wick burner it is about two-thirds of the oil necessary with a one-wick burner to produce the same quantity of light. The consumptions of oil per unit of effective intensity increase only slowly with the diameter, for they are: 24·93, 25·20, 25·87, 26·81, 27·75, 28·96. The conclusion is that, with flames produced from Scotch paraffin oil, the effective luminous intensity does not increase as rapidly as the consumption of oil, considering one burner relatively to a larger burner. The result depends upon several circumstances, chiefly upon the law according to which the specific intensity of the flames increases, and upon the value of their co-efficient of transparency; and with different data may be modified. With colza oil, or with gas, for example, the intensity might be proportional to the consumption, or might follow a law of increase of greater or less rapidity.

The Author considers it interesting to compare the intensity of the electric light with that from a mineral-oil flame, and makes an analogous calculation for the light of the sun. The electric light produced by magneto-electric machines, as chiefly employed in lighthouses, is considered as occupying nearly the volume of a small sphere, 1 centimètre in diameter, with an intensity of 200 Carcel burners. Its apparent surface is therefore 0·7854 square centimètre, and its intensity per square centimètre 255 burners, that is, 554 times that of a five-wick lamp, which has been found to be 0·460. Supposing a co-efficient of transparency in each case, the specific intensity of the electric light would be represented by 411, that of the sun (from calculation of observed values) 2,689; so that the intensity of solar light would be about 6½ times that of the electric light, or 24,000 times that of a five-wick lamp. Undue importance is not, of course, to be attributed to these calculations.

The light emitted by a lamp with circular wicks presents in all

horizontal directions the same intensity, but in directions inclined to the vertical plane very various results are obtained. Above the horizontal plane the intensity diminishes, perhaps because the apparent surface of the flame diminishes, perhaps because the superior portions are less heated, and are consequently less brilliant. This decrease of intensity is still more rapid beneath the horizontal plane, for the summit of the burner hides portions of the flame. The law of these variations is doubtless not the same for all lamps, since it depends on the form and height of the flame. In a four-wick lamp the intensity represented by 1 in a horizontal direction becomes, in rising by 10° to the vertical, 0·995, 0·985, 0·945, 0·890, 0·820, 0·745, 0·685, 0·625, 0·600; and falling below the horizontal by 10°, 0·980, 0·935, 0·790, 0·490, 0·200, 0·090, 0·030, 0·000, 0·000. If there is taken for unity of surface the small square having for its side the length of a degree of arc, and instead of considering the light emitted around the horizon, that is calculated which is comprised between two vertical planes passing through the axis and making an angle of 1°, it will be only necessary to multiply the result by 360 to obtain that for the entire circumference. The products for each portion of a zone of 10° are the co-efficients by which it is necessary to multiply the intensity of the lamp placed in the focus, in order to find the quantities sent by the lamp through each of the eighteen zones considered, and to find also the quantity of light received by each of the three portions composing an apparatus. It is sufficient to know, for the different orders, the position and amplitude of the angles occupied by each of these parts, to calculate the total co-efficient which corresponds to that angle. Multiplying this co-efficient by the intensity of the lamp, there is obtained the quantity of light in action. This quantity is, however, subject to losses in traversing the optical apparatus. These losses are of three kinds: that due to reflection from the surface of the glass, and depending on the angle of incidence, for angles of 0°, 15°, 30°, 45°, 60°, 75° being 0·050, 0·052, 0·058, 0·075, 0·120, 0·230, except in the case of catadioptric rings, when these figures are multiplied by $\frac{3}{2}$, there then being three instead of two deviations of the luminous rays; that due to absorption of light by the glass, for which in practice 0·03 per centimètre of glass traversed may be taken; finally, the loss due to the horizontal joints of dioptric lenses, varying from 0·01 to 0·04, according to the order. The co-efficient m for any order of fixed-light apparatus is given under the best conditions by the formula $\frac{2}{3}\left(\frac{f}{\sqrt{d}}\right)^{1\cdot15}$, where f is the focal distance of the apparatus and d the diameter of the flame. With regard to the relation between the intensity of the fixed light and that of a flashing light, if A be intensity of the flash along the axis, y the intensity at another point of the focal plane situated x degrees from the axis, a the horizontal semi-divergence, then $y = A\left(1 - \frac{x^2}{a^2}\right)$.

If a be the intensity of the fixed light, and ϕ the angle subtended by the annular lens, $A = a\frac{3\phi}{4a}$. For catoptric apparatus the coefficient by which it is necessary to multiply the intensity of the lamp is $k = 18 \cdot 5 \frac{f^{1 \cdot 6}}{d^{1 \cdot 2}}$, where f is the focal distance and d the diameter of opening.

The Author then proceeds to the consideration of 'scintillant' lights and the theory of vision connected therewith, and deals finally with nocturnal transparency of the atmosphere, for various stations for which curves have been constructed. A list is added of all the lighthouses on the French coast, their position, the nature of each light, the number of its burners, and the distance in nautical miles to which it carries in foggy, medium, and clear weather.

P. H.

Recent Investigations on the Composition of Coal Gas and Hydrocarbons. By M. BERTHELOT.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 871.)

On examining the illuminating gas supplied by the Compagnie Parisienne to the city of Paris, M. Berthelot detects the presence of several hydrocarbons, and determines their relative quantities as follows:—

Benzine vapour can be promptly and accurately measured by the decrease of a given volume of coal gas when exposed to the action of concentrated nitric acid. Paris gas yields from 3 to $3\frac{1}{2}$ per cent. in volume of benzine vapour.

Let the gas be first brought into contact with boiled sulphuric acid, which (allowing a proper deduction for moisture) only absorbs in hydrocarbons $\frac{1}{2000}$ part of the original volume; let it be afterwards exposed to the action of bromine; it will then undergo a reduction of $3\frac{1}{2}$ per cent. in volume. If bromine alone be used the decrease of volume will be $3 \cdot 7$ per cent. Hence it follows that the hydrocarbons non-absorbable by acids, though by bromine, such as ethylene, acetylene, and homologous compounds, are only contained in Paris gas in a minute proportion, which does not exceed from $\frac{2}{1000}$ to $\frac{3}{1000}$ part. In previous experiments M. Berthelot has measured the relative quantities of the latter hydrocarbons by combining ethylene with iodine and acetylene with copper.

Now, to ascertain the proportions of the other hydrocarbons, the gas is passed first through diluted sulphuric acid and thence on pumice stone impregnated with concentrated sulphuric acid. The diluted liquor separates into two layers—inferior No. 1, superior No. 2; the liquor trickling from the pumice yields also a lower portion, No. 3, and an upper portion, No. 4.

No. 1 is a tar-like compound (4 to 5 grammes per 100 cubic mètres = 17·2 to 21·8 grains per 1,000 cubic feet), which does not yield any volatile matter when heated to 400° C. (= 752° Fahr.). Its chemical composition will be ascertained by future researches.

No. 2 submitted to methodic distillation yields 0·25 gramme per 100 cubic mètres (= 1·1 grain per 1,000 cubic feet) of acetone, which establishes the presence of allylene in coal gas.

No. 3, when diluted, shows a moist precipitate of hydrocarbons amounting to 25 grammes per 100 cubic mètres (= 109·2 grains per 1,000 cubic feet). This precipitate, submitted to fractional distillation, exhibits the following composition per cwt.:—

Benzine and toluene	2
Mesitylene (volatilised between 320° and 338° Fahr.)	5
Cymene (volatilised at 356° Fahr.)	20
Tricrotonylene (volatilised between 428° and 464° Fahr.)	30
Colophene (volatilised between 572° and 608° Fahr.)	32
Fixed residual product at 608° Fahr.	5
Intermediate compounds and loss	6
	100

No. 4, diluted and distilled, yields isopropylic alcohol, which bears testimony to the existence of propylene in illuminating gas.

It must be understood that, with the exception of benzine, the hydrocarbons embodied in No. 3 are not contained effectively in coal gas, but are the transformed products of still more volatile hydrocarbons therein contained, when acted upon by SO^3H^2O. Thus mesitylene derives from allylene, formerly contained in gas, cymene and colophene from terene, tricrotonylene from crotonylene, &c.

From what precedes can be inferred the following composition of 1,000,000 cubic feet of Parisian gas, for that portion absorbable by bromine:—

Benzine vapour	from 30,000 to 35,000	
Acetylene	about 1,000	
Ethylene	from 1,000 to 2,000	
Propylene	2·5	181 as a minimum.
Allylene	8	
Butylene and homologous compounds	traces	
Crotonylene	31	
Terelene	42	
Several hydrocarbons in a polymeric state	83	
Diacetylene and corresponding hydrocarbons	15	

Referring to previous investigations on the matter, M. Berthelot states that one of the principal experimental laws of the reciprocal action of pyrogeneous products runs thus: Any one of the four fundamental hydrocarbons, viz., acetylene, ethylene, methyl, and formene, when in presence of hydrogen at a red heat, generates any one of the other three. Another law is that the fundamental hydrocarbons and the polymerous compounds derived separately

from each of the two first ones, combine two-by-two at a red heat. Thus M. Berthelot has proved that benzine unites with acetylene and produces styrolene; acetylene with styrolene produces naphthaline; acetylene with naphthaline produces acenapthene; styrolene with benzine produces anthracene; acetylene with ethylene produces crotonylene; acetylene with propylene produces terene—all substances to be found in coal gas or coal tar.

These facts and laws give the key to the somewhat complicated composition of coal gas. The first compounds yielded by the coal in the course of distillation separate into the four fundamental hydrocarbons, which in their turn, by mutual combination at a red heat, reproduce the whole series of pyrogeneous products.

A. S.

On a Method of Determining the Intensity and the Law of the Increase of Pressure in the interior of a Gun in relation to the Time. By GENERAL A. MORIN.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 654.)

The experiments of M. Tresca, showing that solids when subjected to high pressures flow out like liquids, have led, since 1866, to various attempts to employ this property for measuring the tension of the gas produced by the combustion of gunpowder. Messrs. De Reffye and Pothier found that a cylinder of lead introduced into the side of a gun flowed out, under the action of the pressure produced by the discharge, in a jet of the form of a truncated cone. The softness of the lead, however, causes it to flow out so readily that it is not suitable for measuring high tensions. The Author has tried similar experiments with red copper and tin, having selected these metals as being harder than lead, but very ductile and easily obtained in a pure state. Red copper proved too hard to give good results; but tin appears to satisfy every requisite. The jets obtained with the tin increase in length in proportion to the intensity of the pressure. The law of this increase is given by the formula

$$P = 133\ L,$$

where P is the pressure, in lbs. per square inch, on the base of the tin cylinder and on the internal sides of the gun, and L the length of the jet in inches.

This law having been verified by experiment for pressures up to 63·49 tons per square inch, it is evident that a cylinder of tin 0·55 inch in diameter would suffice to measure with great exactness the highest pressures produced in the interior of a gun.

Various means have been employed for ascertaining the laws of the motion of projectiles in the interior of a gun; and the experi-

ments of Captain Ricq determine the laws of the motion imparted to a rod, furnished with a piston, the relations of whose surface and mass to that of the projectile are known, from which the tensions of the gases produced by the discharge are deduced. By prolonging the conical gauge, containing the cylinder of tin, by a small cylindrical channel, in which a well-fitting rod could be placed in contact with tin, the rod would be expelled simultaneously with the jet when the gun is discharged; and it would record its motion, which would correspond with that of the jet, by an apparatus similar to that used by Captain Ricq; so that the pressures exerted, and the exact instant of the action of each, would be given, from which the law of their increase could be deduced.

L. V. H.

On the Effect of Thin Plates of Iron used as Armatures for Electro-Magnets and a New Form of Induction Coil.

By John Trowbridge.

(American Journal of Science and Arts, 3rd series, vol. xi., p. 361.)

In a Paper presented to the American Academy of Arts and Sciences, in April 1875, the Author showed that the application of armatures to two straight electro-magnets, which formed the primary circuit of a Ruhmkorff coil, more than doubled the strength of the induction current produced by breaking the primary circuit. These experiments were made with solid iron cores, for which, in the present series, bundles of fine iron wires were substituted. The resistance of each of the two induction coils was 6,000 ohms, and that of each of the straight electro-magnets 0·34 ohm. The diameter of the bundles of fine iron wires constituting the cores was 5 centimètres, and the length of the electro-magnets 28 centimètres. The first experiments were made with solid armatures. Without the armatures a deflection (to which the electric value may be considered proportional) of 75 scale-divisions was obtained; with the armatures, 85 scale-divisions. With twenty iron plates $1\frac{1}{4}$ inch in thickness, the deflection increased to 386·6, or a gain of 400 per cent. Taking plates $\frac{1}{24}$ inch in thickness, the increase was nearly proportional to the number of plates, but a point was reached where there was no additional effect. Plates of $\frac{1}{32}$ inch were also used, but no advantage resulted in their employment over those of $\frac{1}{24}$ inch. The striking distance was next measured and found to be, without armatures 14·5 centimètres, and with armatures 31·3 centimètres. The lengthening of the spark was not shown when the spark leaped directly between the poles of the induction coil; the increase in quantity and electro-motive force was only made manifest to the eye by the employment of condensers in the secondary circuit,

and the results of lengthening the spark given above were obtained by the employment of a Leyden jar of large capacity. It may be said to have been proved experimentally, that the application of thin plates of soft iron upon the poles of two straight electro-magnets, with bundles of fine iron wires for cores, increases the strength of the spark 400 per cent.; the length of the spark is increased 100 per cent. when condensers are also used; and that instead of distributing the fine wire of a Ruhmkorff coil upon a straight electro-magnet, as is done at present, this wire should be distributed equally upon two straight electro-magnets whose poles should be provided with armatures of bundles of thin plates of soft iron.

P. H.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1875–76.—Part III.

END OF VOL. XLV.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS,
STAMFORD STREET AND CHARING CROSS.